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ANALYSIS OF CHEMICAL LASERS

Volume 3

One-Dimensional Laser and Mixing Program Guide

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The One-Dimensional Laser and Mixing Program (ODLAMP) is described for analyzing multi-species lasing in a chemically reacting one-dimensional stream with mass addition. Mass is assumed to be injected (at a predescribed rate) from each of two separate streams, into a primary lasing stream. Lasing due to P-transitions (i. e., transitions proceeding from (v+1,J-1) to (v,J)) is treated. Both the analysis and computer programs are presented, including an input guide, sample calculation and flow chart.

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FOREWORD

This document is Volume III of a five-part final report which presents the results of work performed by the Lockheed Huntsville Research & Engineering Center under Contract DAAH01-74-C-0173 for the Propulsion Directorate, U. S. Army Missile Research, Development and Engineering Laboratory, U. S. Army Missile Command, Redstone Arsenal, Alabama. This work was monitored by Mr. William D. Martin of the Propulsion Directorate.

The period covered by this report was from 20 September 1973 to 30 June 1974.

The final report for this contract is comprised of the following volumes:

1. Laser and Mixing Program Theory and User's Guide (LMSC-HREC TR D390222-I)
2. Chemical Laser Flow Analysis (LMSC-HREC TR D390222-II)
3. One-Dimensional Laser and Mixing Program Guide (LMSC-HREC TR D390222-III)
4. Method of Characteristics Laser and Mixing Program Theory and User's Guide (LMSC-HREC TR D390222-IV)
5. Rotational Relaxation Effects (LMSC-HREC TR D390222-V).

This report documents the work done to modify and update the capabilities of OD-LAMP and supersedes report Technical Report RK-CR-73-2. A summary of the modifications incorporated in this report may be found in the Introduction.

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NOMENCLATURE

Symbol	
A	reaction rate constant (cm-particle-sec units)
B	activation energy (cal-mole^{-1})
C_1	gravitational constant (980.6 cm-sec^{-2})
C_2	numerical conversion constant (2.389 x 10^{-8} cal-sec-gm^{-1}-cm^{-2})
f	catalytic species weighting factor
F_i	Y_i/W_i (mole$_i$-gm^{-1})
ΔG	Gibbs free energy (cal-mole^{-1})
h	enthalpy (cal-mole^{-1})
I	internal radiation intensity (cal-cm^{-2}-sec^{-1})
K_p	equilibrium constant
k_f	reaction rate forward rate coefficient
$\mathscr{L}$	width of optical cavity (cm)
L	width of stream (cm)
m	flow rate (gm-cm^{-1}-sec^{-1})
p	pressure (torr)
Q	radiation contribution to energy balance (cal-cm^{-1}-sec^{-1})
r_o, r_L	mirror reflectivities
$\mathfrak{R}$	universal gas constant (8312.97 dyne-cm-g mole^{-1}-K^{-1})
R	species production (deletion) due to stimulated emission (mole$_i$-cc^{-1}-sec^{-1})
t	time (sec)
T	temperature (K)
W	molecular weight (gm-mole^{-1})
u	velocity (cm-sec^{-1})
$\dot{w}_i$	species chemical production (deletion) rate (mole$_i$-cc^{-1}-sec^{-1})
x	longitudinal distance (cm)
Y_i	mass fraction

NOMENCLATURE (Continued)

Greek

α	active medium gain (cm^{-1})
$\bar{\alpha}$	threshold gain (cm^{-1})
β	defined by Eq. (10a)
ϵ	molar photon energy ($cal\text{-}mole^{-1}$)
δm	injection flow rate ($gm\text{-}cm^{-1}\text{-}sec^{-1}$)
ρ	density ($gm\text{-}cc^{-1}$)

Subscript

i	refers to i^{th} species
m	refers to average value
L	refers to lower laser level
U	refers to upper laser level
1	refers to initial integration station
2	refers to final integration station

Superscript

–	denotes average
'	refers to secondary stream (stream 2)
''	refers to secondary stream (stream 3)

Section 1
INTRODUCTION

The importance of continuous wave (cw) chemically pumped lasers has generated a number of investigations designed to enhance the understanding of laser devices and their potential. These investigations have led to the development of sophisticated chemical laser models (Refs. 1 through 3) which couple the fluid mechanic, nonequilibrium chemistry and laser radiation processes. Unfortunately, however, these computer models require a large amount of computer time to analyze one set of conditions. Consequently, when performing design studies where many variables must be investigated the computer time requirements are considerable.

In this report a one-dimensional chemical laser model is presented which approximates the two-dimensional effects of mixing. Since it is one-dimensional and requires solution along only one streamline as opposed to the 10 to 20 streamlines required in two-dimensional mixing analyses, computer run times are reduced significantly.

As Fig. 1 shows, mass from two dissimilar secondary streams is injected into a primary lasing stream at some prescribed rate which varies with longitudinal distance. Excitation of the active medium traversing a Fabry-Perot optical cavity is achieved by the highly exothermic nonequilibrium reactions occurring in the cavity region.

The program can handle three simultaneously lasing species each of which in turn can have an arbitrary number of vibrational levels. Lasing at either fixed-J or shifting-J rotational lines can be treated. The transition gains (from $v+1, J-1 \rightarrow v, J$) are computed accounting for the effects of both Lorentz and Doppler broadening. In addition, the program can handle mirror absorptivities and reflectivities which vary with longitudinal position.

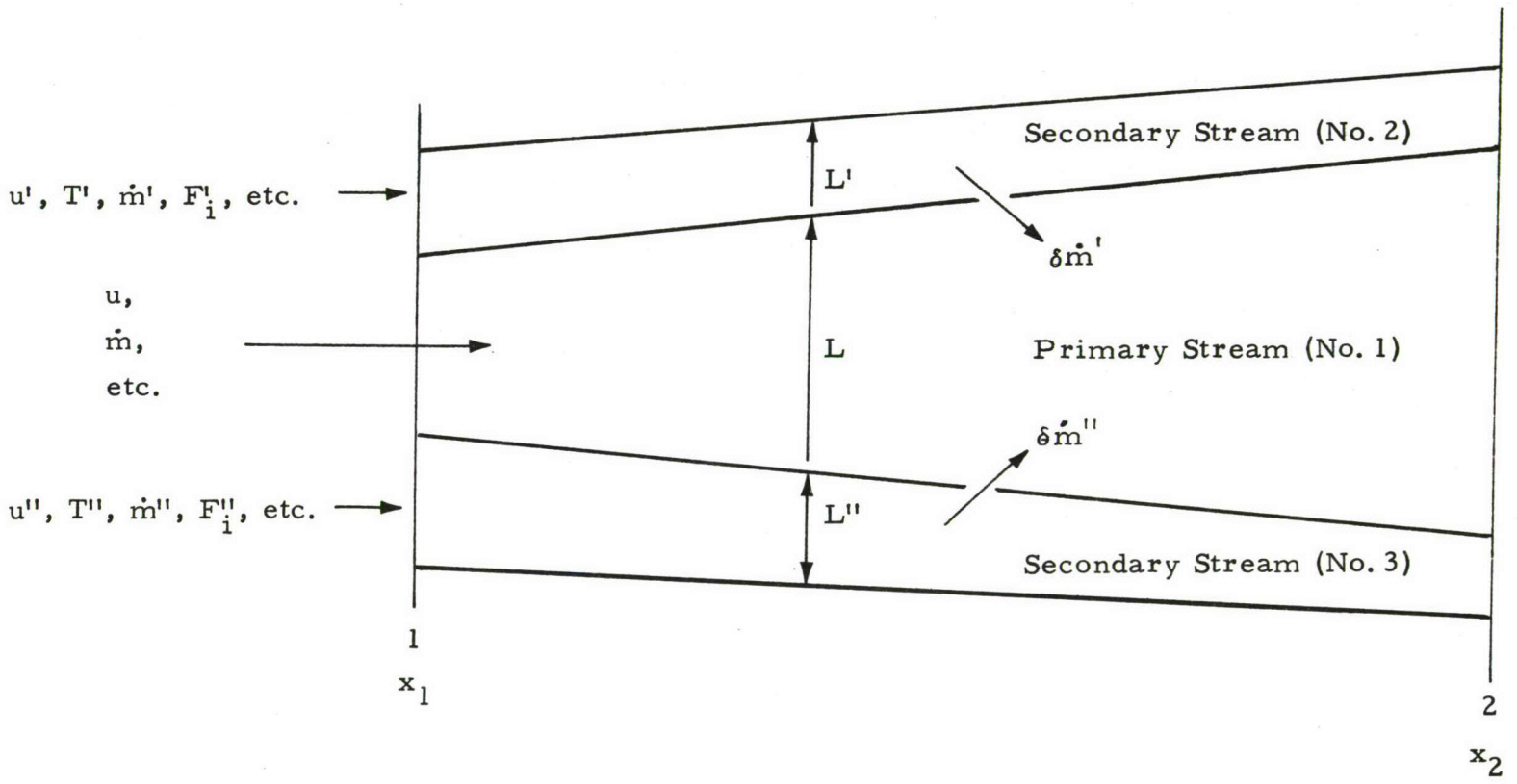

Fig. 1 - Flow Schematic

The program allows any chemical reaction mechanism to be investigated as long as the rate coefficients and species thermodynamic data are known. Thermodynamic data taken directly from the JANNAF thermochemical tables is input in tabular form.

In this report the governing equations and a complete description of the computer program are given including an input guide, and a sample calculation. The output of the computer program gives the longitudinal distribution of pressure, velocity, temperature, species mole fractions, laser transition gains, radiative intensities, and laser power output.

Modifications made and incorporated in this report are as follows:

- Page 2-2 — Equations 2a, 2b and 2c have been updated to include the wall force term in the momentum equation. This term was inadvertently not included in the original document.
- A new Section 7 — Program Usage and Comparison has been added. This section briefly discusses the program operational experience to date and shows a comparison between the ODLAMP and LAMP predictions for the same sample case.
- Page B-5 — The input has been modified to only require input of the collision broadening constants (Card 20) when Lorentz and Doppler broadening are to be used (LFLAG = 1, Card 1).
- Appendix C — Additional sample input and output have been provided for the multi-specie lasing case (DF and CO_2).

Section 2
ANALYSIS

It is assumed that the injection rates for each of the two secondary streams into the primary lasing stream are known as a function of longitudinal position. The computer program then solves for the fluid mechanic and chemical properties. The flow properties (pressure, velocity, temperature, species concentrations and cross sectional area) are defined using the conservation of momentum, energy and mass relationships along with the continuity equation and equation of state. Closure is obtained with the condition that one flow parameter (either pressure, temperature or cross-sectional area) is known.

Referring to Fig. 1 the governing equations for the three streams are:

Mass

Stream (1) – Primary*

$$(\rho u)_1 \left(\frac{\partial F_j}{\partial x}\right)_1 = \dot{w}_{i_2} + R_{i_1} \tag{1a}$$

Stream (2) – Secondary

$$F_i' = \text{constant} \tag{1b}$$

Stream (3) – Secondary

$$F_i'' = \text{constant} \tag{1c}$$

*In Eq. (1a) note that $\dot{w}$ is evaluated at the forward integration point (station 2). This is because an implicit scheme is used to analyze the chemistry effect.

Momentum

Stream (1)

$$\dot{m}_2 u_2 = \dot{m}_1 u_1 + \delta m' u_1' + \delta m'' u_1'' - C_1 (p_2 L_2 - p_1 L_1) + C_1 p_m (L_2 - L_1) \quad (2a)$$

where $$p_m \equiv \frac{p_1 + p_2}{2}$$

Stream (2)

$$\dot{m}_2' u_2' = \dot{m}_1' u_1' - \delta m' u_1' - C_1 (p_2' L_2' - p_1' L_1') + C_1 p_m' (L_2' - L_1') \quad (2b)$$

Stream (3)

$$\dot{m}_2'' u_2'' = \dot{m}_1'' u_1'' - \delta m'' u_1'' - C_1 (p_2'' L_2'' - p_1'' L_1'') + C_1 p_m'' (L_2'' - L_1'') \quad (2c)$$

Energy

Stream (1)

$$\dot{m}_1 \left(\frac{h_1}{\overline{W}_1} + C_2 \frac{u_1^2}{2} \right) + \delta m' \left(\frac{h_1'}{\overline{W}_1'} + C_2 \frac{u_1'^2}{2} \right) + \delta m'' \left(\frac{h_1''}{\overline{W}_1''} + C_2 \frac{u_1''^2}{2} \right) = m_2 \left(\frac{h_2}{\overline{W}_2} + C_2 \frac{u_2^2}{2} \right) + Q_1 (x_2 - x_1) L \quad (3a)$$

Stream (2)

$$\left(\frac{h_1'}{\overline{W}_1'} + C_2 \frac{u_1'^2}{2} \right) = \left(\frac{h_2'}{\overline{W}_2'} + C_2 \frac{u_2'^2}{2} \right) \quad (3b)$$

Stream (3)

$$\left(\frac{h_1''}{\overline{W}_1''} + C_2 \frac{u_1''^2}{2} \right) = \left(\frac{h_2''}{\overline{W}_2''} + C_2 \frac{u_2''^2}{2} \right) \quad (3c)$$

Continuity

Stream (1)

$$\dot{m}_2 = \dot{m}_1 + \delta m' + \delta m'' \tag{4a}$$

Stream (2)

$$\dot{m}_2' = \dot{m}_1' - \delta m' \tag{4b}$$

Stream (3)

$$\dot{m}_2'' = \dot{m}_1'' - \delta m'' \tag{4c}$$

where $\dot{m} = \rho u L$

State

$$P = \frac{\rho \Re T}{W} \tag{5}$$

Threshold Condition

$$\bar{\alpha}(x) = - \frac{\ell n (r_o r_L)}{2\mathcal{L}} \tag{6}$$

Gain (Along Streamline)

$$\alpha_{i=L} = \epsilon_L \rho (S_{U,L} F_U - S_{L,U} F_L) \tag{7}$$

where $S_{U,L}$ and $S_{L,U}$ are given by Eqs. (2.29) and (2.30) in Ref. 1 for the case of Doppler and Lorentz broadening. In the expressions given above the non-superscripted parameters refer to properties in the primary stream. The constants C_1 and C_2 have been included in order to make the equations dimensionally consistent based upon the units given in the Nomenclature. The parameters R and Q account for lasing influences upon the mass and energy relations, respectively, and are equal to zero when $\alpha_i < \bar{\alpha}$. The subscripts U and L refer to the upper and lower laser levels, respectively.

The species mass fractions computed from Eq. (1a) do not take into account the mass injected between station x_1 and x_2, consequently they must be modified. This is done as follows: The mass fractions, Y_i, are first computed at station x_2 from Eq. (1a). Then they are modified to account for the mass injected between x_1 and x_2 from

$$Y_{i_2} = \frac{\dot{m}_i}{\dot{m}_1 + \sum_{j=1}^{2} (\delta m \, \Delta x)} \, Y'_{i_2} \tag{8}$$

where Y'_{i_2} is the mass fraction computed using Eq. (1a).

The parameters R and Q are functions of the gain, α, and internal intensity, I, and are given by

$$R_{i=L} = \frac{\alpha_L I_L}{\epsilon_L} - \frac{\alpha_{L-1} I_{L-1}}{\epsilon_{L-1}} \tag{9}$$

and

$$Q = \sum_{j=1}^{LS} \sum_{k=1}^{VL} \alpha_{j,k} \beta_{j,k} I_{j,k} \tag{10}$$

where

$$\beta_{j,k} = \frac{h_{j,k} + \epsilon_{j,k} - h_{j,k+1}}{\epsilon_{j,k}} \tag{10a}$$

The double subscript denotes the jth lasing species and its kth vibrational level where LS is the number of lasing species and VL the number of vibrational levels for each lasing species. The internal intensities are obtained by solving a set of simultaneous equations of the form

$$I_{L-1} G_{L-1} - I_L G_L + I_{L+1} G_{L+1}$$

$$- \sum_{k=1}^{VL} I_k G_{LK} = \frac{d\alpha_L}{dx} - G_o \tag{11}$$

where the Gs are given by Eqs. (35) through (39) in Ref. 1. A separate set of simultaneous equations must be solved for each lasing species.

The cavity power (for each lasing line) is then obtained from

$$P_{out_{i=L}}(x) = \int_{x_{th_i}}^{x} I_{out_i} z \, dx \tag{12a}$$

where (case 1)

$$z = 1 \tag{12b}$$

when the optical path lies in the plane containing the three streams, and (case 2)

$$z = \frac{L + L' + L''}{(L + L' + L'')_{x=0}} \tag{12c}$$

when the optical path is perpendicular to the plane containing the three streams. In Eq. (12a)

$$I_{out_{i=L}} = \alpha_i I_i \mathscr{L} \tag{13}$$

The total output power (per initial width of three streams for case 1 and per unit height of nozzle bank for case 2) is then

$$P_{out} = \sum_{j=1}^{LS} \sum_{i=1}^{VL} P_{out_{i,j}} \tag{14}$$

Section 3

CHEMICAL REACTION RATE EQUATIONS

3.1 REACTION RATES

The production rates for all chemical species are calculated in the usual fashion. The same treatment is applied to the various vibrational levels of reacting molecules, and of the lasing molecules in particular, that is, vibrational levels are treated as individual chemical species.

Twelve types of reaction or vibrational energy transfer mechanisms are considered as possible contributors to the calculation of the net rate of production, $\dot{w}_i$:

Reaction type

(1, 7)	A + B	$\rightleftharpoons$	C + D	[1]
(2, 8)	A + B + M	$\rightleftharpoons$	C + M	[2]
(3, 9)	A + B	$\rightleftharpoons$	C + D + E	[3]
(4, 10)	A + B	$\rightleftharpoons$	C	[4]
(5, 11)	A + M	$\rightleftharpoons$	C + D + M	[5]
(6, 12	A + M	$\rightleftharpoons$	C + M	[6]

Reaction types (7) through (12) correspond to reaction types (1) through (6), but proceed in the forward direction only.

The net rate of production for all reactions is given below in the form $\dot{w}^{(j)} = RP^{(j)} - RM^{(j)}$ which are the symbols used in the computer program.

$$1.\quad \dot{w}^{(j)} = k_f \rho^2 F_A F_B - \frac{k_f \rho^2 F_C F_D}{K_p} \qquad (15a)$$

$$2.\quad \dot{w}^{(j)} = k_f \rho^3 F_A F_B F_M - \frac{k_f \rho^2 F_C F_M}{K_p \Re T} \tag{15b}$$

$$3.\quad \dot{w}^{(j)} = k_f \rho^2 F_A F_B - \frac{k_f \rho^3 F_C F_D F_E \Re T}{K_p} \tag{15c}$$

$$4.\quad \dot{w}^{(j)} = k_f \rho^2 F_A F_B - \frac{k_f \rho F_C}{K_p \Re T} \tag{15d}$$

$$5.\quad \dot{w}^{(j)} = k_f \rho^2 F_A F_M - \frac{k_f \rho^3 F_C F_D F_M \Re T}{K_p} \tag{15e}$$

$$6.\quad \dot{w}^{(j)} = k_f \rho^2 F_A F_M - \frac{k_f \rho^2 F_C F_M}{K_p} \tag{15f}$$

To reduce round-off and truncation errors, $RP^{(j)}$ and $RM^{(j)}$ for each reaction are computed separately. All contributions to the molar rate of production of a given species are then computed and added algebraically to form $\dot{w}_i$. Since reaction types (7) through (12) proceed in the forward direction only, the second term on the right-hand sides of Eqs. (15a) through (15f) is disregarded in calculating the contributions to $\dot{w}_i$.

In reactions (2), (5) and (6) as well as in (8), (11) and (12), M denotes the catalytic species which can be specified. In case of reactions (2, 8), (5, 11) and (6, 12) the situation often occurs where for various catalytic species the respective rate constants differ only by a constant multiplier. These multipliers can be considered as third body efficiencies or weighting factors. If such a case is encountered, the third body species mole mass ratio F_M becomes effectively a fictitious mole mass ratio, consisting of the weighted sum over all those species having a nonzero weighting factor, i.e.,

$$F_M = \sum_i f_i F_{M_i} \tag{16}$$

where f_i are the weighting factors.

3.2 RATE CONSTANTS

The forward rate constant k_f is generally expressed in Arrhenius form. The equilibrium constant, K_p, is determined from the Gibbs free energy difference

$$\ln K_p = - \Delta G/\Re T \tag{17}$$

For speed in computation the rate constants are divided into five types:

Rate Coefficient Type

(1) $k_f = A$ (18a)

(2) $k_f = AT^{-N}$ (18b)

(3) $k_f = A \exp(B/\Re T)$ (18c)

(4) $k_f = AT^{-N} \exp(B/\Re T)$ (18d)

(5) $k_f = AT^{-N} \exp(B/\bar{\Re} T^M)$ (18e)

Section 4
THERMODYNAMIC PROPERTIES

To make maximum usage of the current technology of finite rate formulations, the vibrational levels of respective excited molecules are treated as individual chemical species. This, of course, requires separate specification of the thermodynamic properties for molecules in each vibrational level. This is accomplished by the assumption that the molecular rotation is in equilibrium at the translational temperature but allows the molecules to vibrate independently of the translational temperature. Accordingly, each molecule is permitted to vibrate independently corresponding to the energy in its respective vibrational level.

Thermodynamic data is input directly in tabular form. The thermodynamic properties (specific heat, entropy and enthalpy) for each species are taken directly from the JANNAF thermochemical tables (Ref. 4) (or other such source) and input to the program as described in Appendix B. Properties are obtained from the tables by linear interpolations on temperature. The Gibbs' free energy is computed from the JANNAF enthalpy, entropy and temperature.

Section 5
PROGRAM OPTIONS

The computer code has been developed around three primary options. They are

1. The longitudinal distribution of temperature in each of the three streams is known a priori.
2. The longitudinal distribution of pressure in each of the three streams is known a priori.
3. The longitudinal distribution of the total cross-sectional area of the three streams is known a priori.

Temperature Option

For the case where the temperature distribution is assumed to be known the calculational procedure is as follows:

1. Species mass fractions are computed using Eqs. (1) and (8).
2. The velocities in the primary and secondary streams are then obtained using Eqs. (3).
3. With the velocities now known the pressures in the three streams can be computed using Eqs. (2).
4. The densities are then found from the equations of state (Eq. (5)).
5. The areas of the three streams are computed from continuity (Eqs. (4).

Pressure Option

For the case when the pressure distribution is assumed to be known the calculational procedure is as shown on the following page.

1. Same as Temperature Option

2. The velocities are computed using Eqs. (2)

3. Temperatures are then computed using the energy equations (Eqs. (3)).

4. Same as Temperature Option

5. Same as Temperature Option.

Area Option

When the area is assumed to be known the solution becomes iterative. The solution follows that for the pressure option case. A pressure at point x_2 is assumed and the area computed and checked against the known area. If the computed and known areas do not agree the assumed pressure at point x_2 is modified. This procedure continues until agreement is reached.

For this option the pressure variations for all three streams are assumed to be identical, but unknown. If the pressure variations are not taken to be identical a unique solution cannot be found.

Section 6
PROGRAM FEATURES

- Dynamic Dimensioning

In order to establish core storage requirements which are sufficient to run a particular case but yet keep from setting aside core storage which is unused, dynamic dimensioning has been incorporated into the ODLAMP code. Prior to compilation of the ODLAMP code, therefore, the variable subscripts used in the common and dimension statements must first be replaced by their appropriate integer values for the particular case being considered. This is done by running the ODLAMP Dynamic Dimensioning Program. This program reads as input the ODLAMP code and the variable subscript names and their integer values. The ODLAMP code is then searched and all variable subscripts are replaced by their respective integer values, thereby generating a new ODLAMP program tape. This tape is then rewound, compiled and executed. The input guide for the ODLAMP Dynamic Dimensioning Program is given in Appendix A.

- Plotting (Page or 4020 plots)

If so desired the user may have plotted selected parameters (e.g., laser power, pressure, species mole fractions, etc.) as a function of distance. This is done by setting IPLOT = 0, 1, 2 or 3. If IPLOT = 0, plots are omitted. If IPLOT = 1 page plots are obtained which gives, after each 50 output stations as well as at laser cutoff, a plot of each of the parameters as a function of distance. If IPLOT = 3 the desired data will be stored on logical unit 4 for subsequent plotting on the 4020. If IPLOT = 2, both page and 4020 plots are obtained. The number and identification of the parameters to be plotted are read in on cards 22 and 23.

- Optical Cavity Width

The user may select as the width of the optical cavity either the width of the three streams which is evaluated locally or a width which is input.

The selection of which option desired is made on card 2. If the width is input it is given by an equation of the form

$$\mathcal{L} = Q_o + Q_1 x + Q_2 x^2$$

where $\mathcal{L}$ and x are in centimeters. The coefficients are read in on card 24.

- Mirror Properties

In order to make the program flexible, mirror absorptivities and reflectivities are treated as variable functions of distance. They are given by equations of the form

$$r \text{ (or a)} = Q_o + Q_1 x + \beta_2 x^2 + Q_3 x^3 + Q_4 x^{-1} + Q_5 x^{-2} + Q_6 \exp(-x/Q_7)$$

The coefficients are read in on cards 8-11.

- Doppler/Lorentz Broadening

An option which allows the user to select either Doppler/Lorentz broadening or Doppler (only) broadening is provided (See card 2). However, it is recommended that the Doppler/Lorentz option be exercised until such time as the user becomes familiar with the conditions where the Doppler (only) broadening approximation is adequate.

- Chemical Kinetic Rates

An output option is provided (card 2) which, if exercised, prints out at all output stations the species kinetic rates, the forward and reverse reaction rates for all chemical reactions and the forward and reverse rate coefficients for all chemical reactions.

- Mixing Rate

The rate at which mass from each of the two secondary streams is injected into the primary lasing stream is assumed to be known a priori as a function of longitudinal position. The mass injection rates are then described by an equation of the form

$$\delta\dot{m} = Q_o + Q_1 x + Q_2 x^2 + Q_3 x^3 + Q_4 x^{-1} + Q_5 x^{-2} + Q_6 \exp(-x/Q_7)$$

where $\delta\dot{m}$ and x are in gm-cm^{-1}-sec^{-1} and cm. The coefficients are read in on cards 6 and 7.

Section 7

PROGRAM USAGE AND COMPARISON

7.1 PROGRAM USAGE

This section briefly describes some of the operational characteristics of the ODLAMP program which have been observed during development and check-out. Relatively little operational experience has been obtained to date other than exercising the various options for selected test cases. Therefore, the comments that follow will probably not cover specific characteristics which will be uncovered as the program is more extensively used.

The various types of cases considered thus far may be summarized as follows:

- Single stream, finite rate chemistry analyses in variable area ducts without laser radiation.
- Simulation of multi-stream viscous mixing of dissimilar streams with finite rate chemistry and no laser radiation.
- Premixed single stream analyses of one lasing specie (HF or CO_2) with both fixed and shifting J levels (Appendix C-1).
- Premixed single stream analyses of two simultaneously lasing species (DF and CO_2) with shifting J levels (Appendix C-2).
- Multi-stream simulation of viscous mixing of dissimilar streams with finite rate chemistry and one lasing species (HF).

Program execution times are naturally a function of linear step size. Logically, larger input step sizes would mean less execution time. However, one must remember that the laser radiation package contained in the program traces discontinuities such as threshold, J shift and cutoff. The program iteratively solves for the axial location of these discontinuities with a high degree of accuracy. The actual step size may be drastically less than that

which is input. Therefore, specific run time characteristics are difficult to ascertain.

Generally, the run times for a radiation calculation are equivalent to those of the LAMP code for a premixed stream where explicit chemistry is used. However, run times for non-radiating cases are drastically reduced due to the utilization of the implicit finite rate chemistry model.

Another observed characteristic is the ability of the program to handle the transition from supersonic to subsonic flow conditions. This provides additional utility where duct flows are of interest.

Generally, the program is relatively free of external "fine tuning adjustments" associated with many numerical techniques and requires few pre-execution calculations to establish input data.

7.2 ODLAMP COMPARISON WITH LAMP (REF. 1)

The ODLAMP (one-dimensional laser and mixing program) is the manifestation of a one-dimensional theoretical simplification of the two-dimensional LAMP (Ref. 1) code. The ODLAMP simulates the two-dimensional viscous mixing by injecting mass at prescribed rates into a primary (lasing) medium. Excitation of the active medium traversing a Fabry-Perot optical cavity is achieved by the highly exothermic nonequilibrium reactions occurring in the cavity region.

A sample case was selected and the data input to both the LAMP and ODLAMP codes. The sample case was selected such that direct comparisons of the flow, chemistry and radiation parameters could be obtained. A hydrogen fluoride (HF) with helium (He) diluent medium was selected. Six vibrational levels of HF were considered in the model. The following table contains the input initial conditions.

$U_i = 5.58 \times 10^3$ m/sec

$P_i = 20$ torr

$T_i = 500^{\circ}K$

Chemical Species	Mole Fraction
HF(0) ⟶ HF(6)	0.0
F	0.1
F_2	0.01
H	0.0
H_2	0.39
He	0.5

Both analyses assumed constant pressure as a function of axial distance and both operated at the rotational level producing maximum gain via J shifting. Fifty reactions and five catalytic species were used.

Figures 7-1, 7-2, and 7-3 show the results of both analyses. Comparisons are shown of the axial distributions of temperature (Fig. 7-1), species mole fractions (Fig. 7-2), and radiation intensity (Fig. 7-3) for both the ODLAMP and LAMP. This check case demonstrates the ability of ODLAMP to duplicate the LAMP one-dimensional premixed calculations.

Figure 7-4 illustrates one of the unique features of ODLAMP, i.e. that of simultaneous lasing from two different molecules. In this case 4 transitions of DF and the 10.6μ line of the CO_2 molecule were all handled simultaneously.

The advantages of dynamic dimensioning used in ODLAMP were demonstrated by the fact that ODLAMP required computer core storage of only 57,000 octal words compared to 134,000 octal words for the LAMP code. This becomes a definite advantage where computer systems use core storage requirements in assigning job priorities.

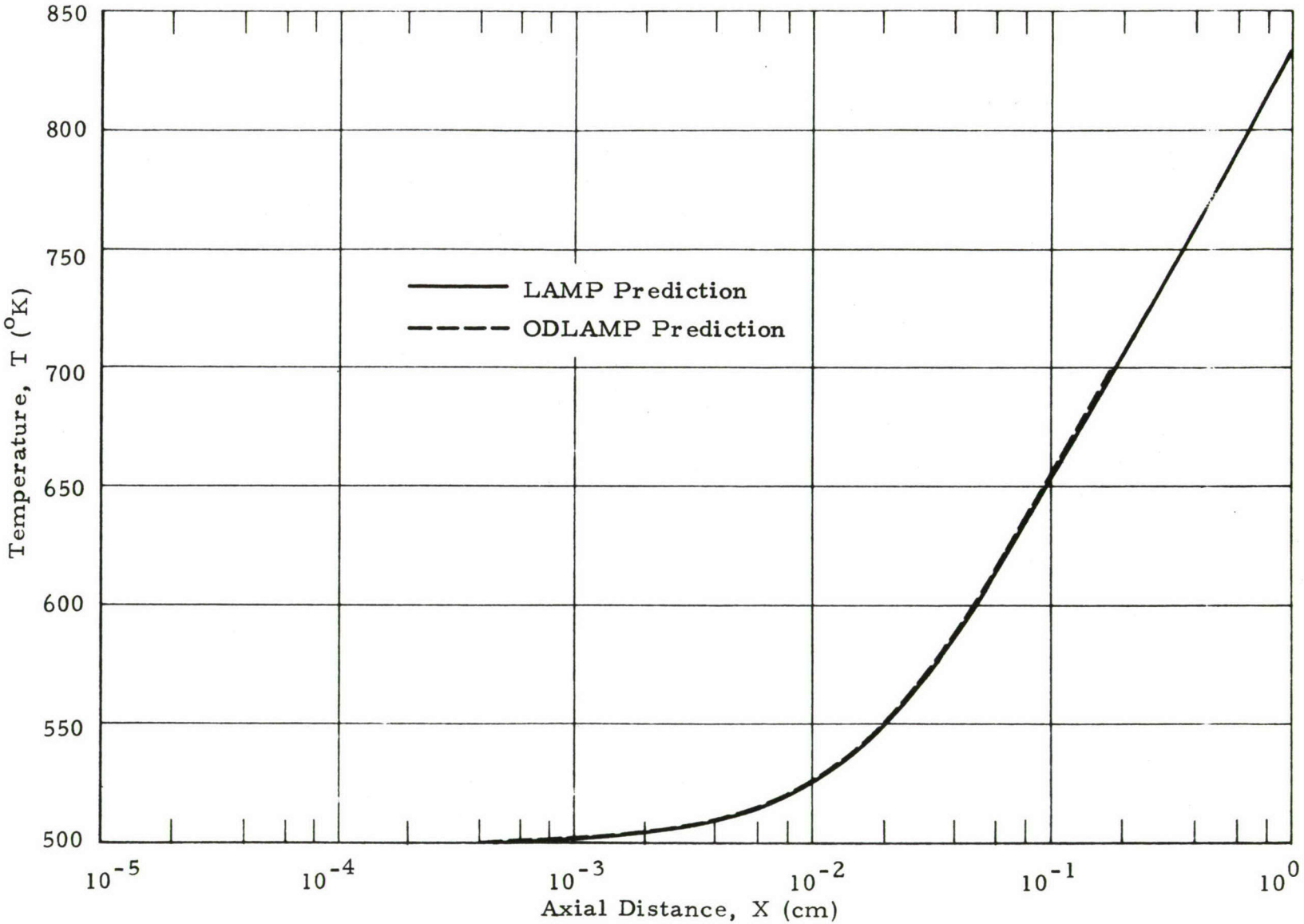

Fig. 7-1 - Comparison of ODLAMP and LAMP Predictions of Axial Temperature Distribution

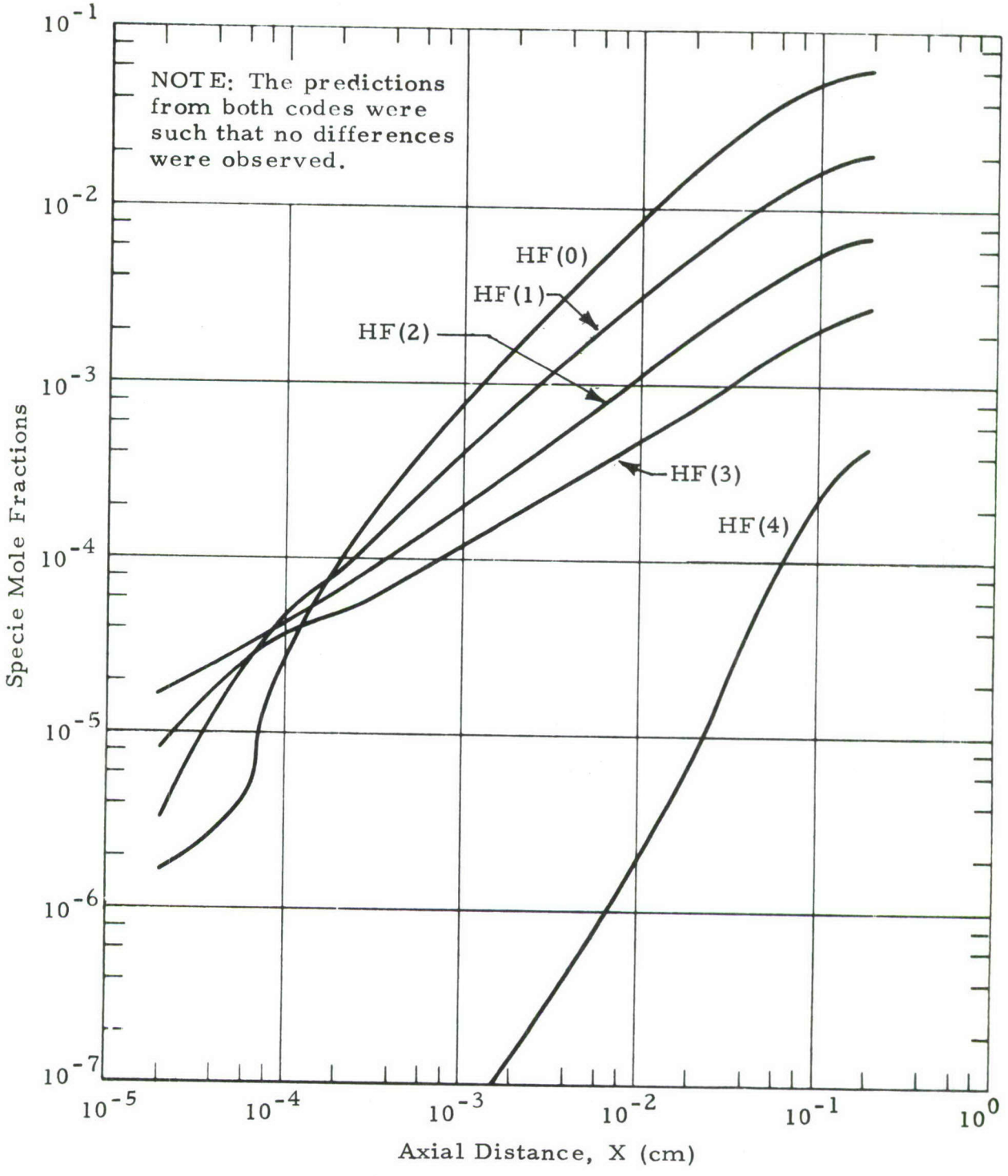

Fig. 7-2- Comparison of ODLAMP and LAMP Predictions of Axial Species Mole Fraction Distribution

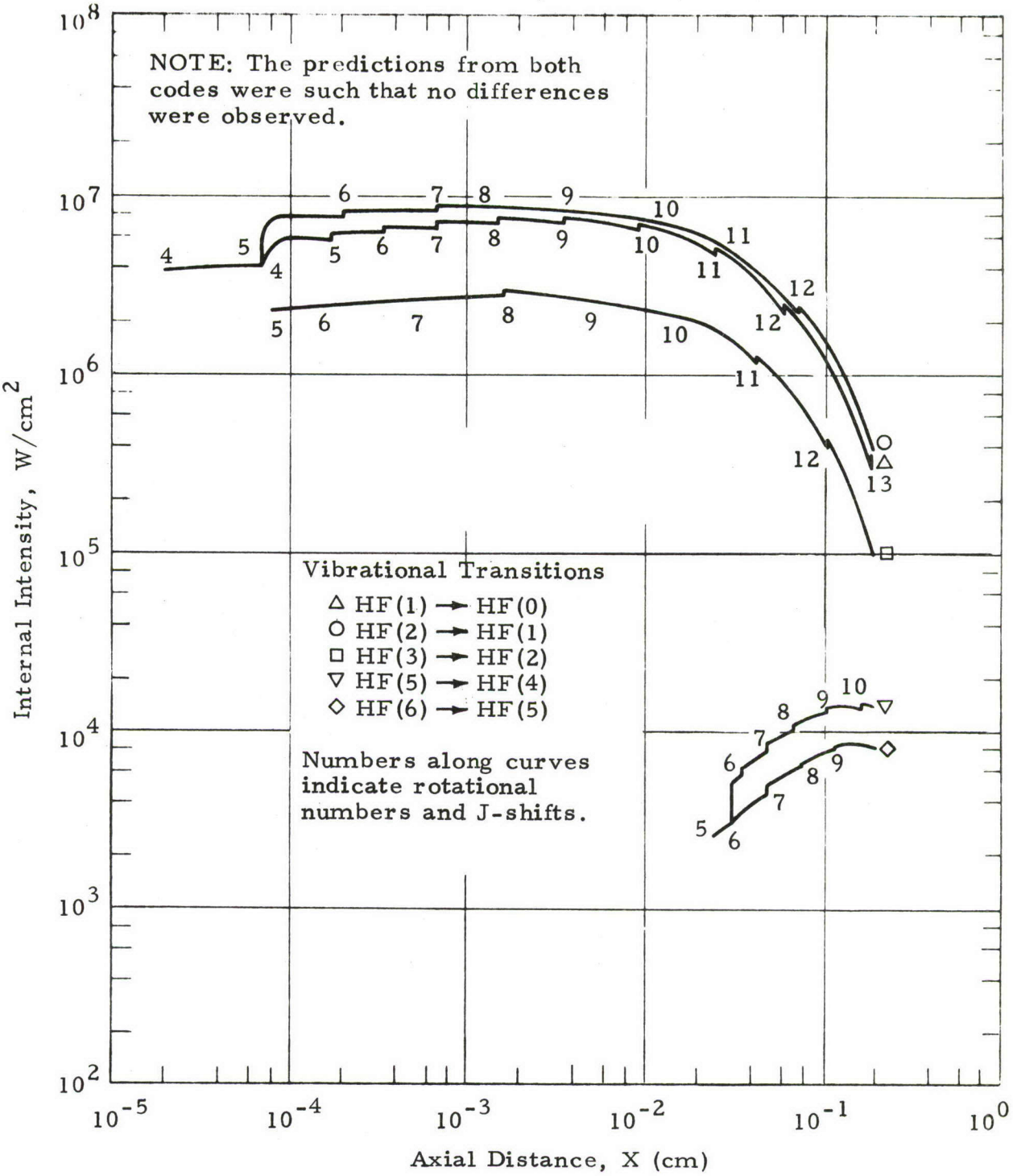

Fig. 7-3 - Comparison of ODLAMP and LAMP Predictions of Axial Radiation Intensity Distributions

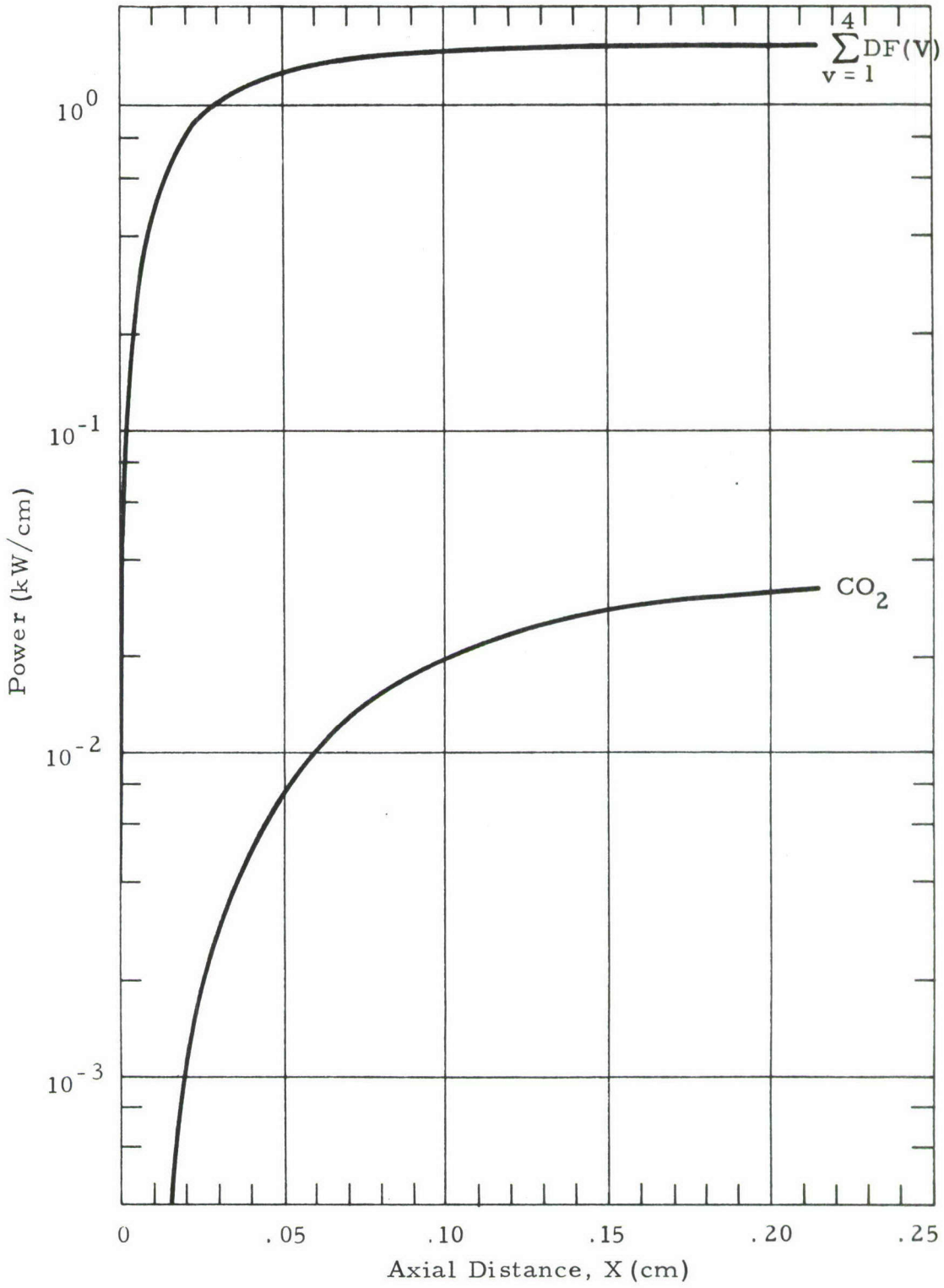

Fig. 7-4 - Calculated Results of Simultaneous Lasing from Four Transitions of DF and the CO_2 Upper to Lower Laser Level

Section 8
REFERENCES

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6. Emanuel, George, W. Dallas Adams and Emily B. Turner, "RESALE-1: A Chemical Laser Computer Program," TR-0172 (2776)-1, The Aerospace Corporation, El Segundo, Calif., 15 March 1972.

7. Emanuel, George, and W. Wallas Adams, "RESALE-2, CO_2, and INHALE," TR-0172 (2776)-5, The Aerospace Corporation, El Segundo, Calif., 25 April 1972.

Appendix A

ODLAMP DYNAMIC DIMENSIONING PROGRAM

(Input Guide)

Appendix A

This appendix contains an input guide for the ODLAMP Dynamic Dimensioning Program. This program establishes the necessary storage requirements for the ODLAMP code.

There are seven (7) required input variables. No specific order of input is required. The data are input in the format of one variable name and its corresponding integer value per data card.

Card	Format	Column	Variable	
1	I10	10	NOP	Number of input variables (7 for ODLAMP)
2-8	A10	1-10	OPT(1)	Variable name (left adjusted)
	I10	I1-20	OPT(2)	Integer value assigned to the variable name (right adjusted)

The following is a list of the required input variables for the ODLAMP program.

1 - NS = Number of chemical species +1

2 - NM = Number of catalytic species

3 - NMS = NS + NM

4 - NT = Number of temperature values in thermodynamic tables

5 - NR = Number of chemical reactions

6 - NX = Total number of lasing transitions for all lasing species

= NVS(1) for 1 lasing species
= NVS(1) + NVS(2) + 1 for 2 lasing species
= NVS(1) + NVS(2) + NVS(3) + 2 for 3 lasing species

7 - NY = NX + 1.

Appendix B

ONE-DIMENSIONAL LASER AND MIXING PROGRAM (ODLAMP)

(Input Guide)

Appendix B

This appendix contains an input guide for the One-Dimensional Laser and Mixing Program (ODLAMP) developed by the Lockheed-Huntsville Research & Engineering Center. This guide, along with the information from the rest of this report, provides the necessary information for the user of this program.

Card	Format	Column	Variable	Description
1	12A6	1-72	HDR	Title card
2	16I5	5	ITYPE	= 1 - T = f(x) known = 2 - P = f(x) known = 3 - A = f(x) known
		9-10	NT	Number of temperature points in thermodynamic tables
		14-15	NS	Number of chemical species
		19-20	NR	Number of chemical reactions
		25	KPWR	= 0 Power off = 1 Power on
		30	NM	Number of catalytic species
		34-35	NV(1)	Number of lasing transitions for each lasing species
		39-40	NV(2)	
		44-45	NV(3)	
		50	LFLAG	= 0 - Doppler broadening = 1 - Lorentz + Doppler broadening
		55	IOUT	= 0 - No species + reaction rate printout = 1 - Species + reaction rate printout (including rate coefficients)
		60	NSTRM	Number of streams (3 max.)
		65	IGAS	= 0 - Gas dynamics and chemistry only = 1 - Includes radiation
		70	KFLAG	= 1 - Condensed laser output = 2 - Detailed output for each transition
		75	IPLOT	= 0 - Omit plots. Do not read cards 22 and 23. = 1 - Page plots only = 2 - Page and 4020 plots = 3 - 4020 plots only
		80	ILASL	= 0 - Width of lasing zone based on overall width of streams = 1 - Width of lasing zone read in as input. Read card 24.

NOTE: Cards 3, 4 and 5 contain the independent variable coefficients. The independent variable type is defined by ITYPE (Card 1). The physical units input are:

ITYPE	Independent Variable	Units
1	Temperature	K
2	Pressure	torr
3	Area	cm

The known axial distributions of the variables on Cards 3 through 11 are input through equations of the form:

$$Q = Q_o + Q_1 x + Q_2 x^2 + Q_3 x^2 + Q_4 x^{-1} + Q_5 x^{-2} + Q_6 \exp(-x/Q_7)$$

Card	Format	Column	Variable	Description
3	8E10.6	1-10, etc.	COEF(1)	STRM1 (T, P, A) coefficients (center)*
4	8E10.6	1-10, etc.	COEF(2)	STRM2 (T, P, A) coefficients (upper) (Read only if NSTRM > 1)
5	8E10.6	1-10, etc.	COEF(3)	STRM3 (T, P, A) coefficients (lower) (Read only if NSTRM = 3)
6	8E10.6	1-10, etc.	COEF(4)	STRM2 Mass ejection rate (g/sec-cm) (Read only if NSTRM >1)
7	8E10.6	1-10, etc.	COEF(5)	STRM3 Mass ejection rate (g/sec-cm) (Read only if NSTRM = 3)
- - - - - - - - - Input Cards 8, 9, 10 and 11 only if IGAS = 1 - - - - - - - - - - - - -				
8	8E10.6	1-10, etc.	COEF(6)	Mirror 1 reflectivity
9	8E10.6	1-10, etc.	COEF(7)	Mirror 2 reflectivity
10	8E10.6	1-10, etc.	COEF(8)	Mirror 1 absorptivity
11	8E10.6	1-10, etc.	COEF(9)	Mirror 2 absorptivity

The following cards contain the thermodynamic data**. The first card contains the species name, molecular weight and heat of formation. The second and remaining cards contain the temperature and corresponding specific heat, entropy and enthalpy for that species. Two temperatures and corresponding thermodynamic data are placed on each card. The input table can contain up to a maximum of 30 temperature points. The data are input exactly as presented in the JANNAF tables.

*Stream 1 is the reacting/lasing stream.

**The order of the species must be identical to the order on card type 21a. Lasing species data must be given first, in the order v=0, v=1, v=2, etc., followed by v=0, v=1, etc., for the second lasing species (if necessary) and similarly for the third lasing species.

Card	Format	Column	Variable	Description
12	A6	1-6	AID	Name of first species
	E10.3	7-16	WTMOLE	Molecular weight
	E10.3	17-26	HF	Heat of formation, h_{298_i} (kcal/mole)
13	E10.3	1-10	TTB	First temperature point (K)*
	E10.3	11-20	CPTB	c_{p_i} (cal/mole-K)
	E10.3	21-30	GTB	S_i^i (cal/mole-K)
	E10.3	31-40	HTB	$h_i - h_{298_i}$ (kcal/mole)
	E10.3	41-50	TTB	Second temperature point (K)*
	E10.3	51-60	CPTB	c_{p_i} (cal/mole-K)
	E10.3	61-70	GTB	S_i^i (cal/mole-K)
	E10.3	71-80	HTB	$h_i - h_{298_i}$ (kcal/mole)

NOTE: 1. There are NS card no. 12s and
2. NT/2 card no. 13s if NT is even,
NT/2+1 card no. 13s if NT is odd.

NOTE: The following set of cards specifies the catalytic species (M1, M2, M3, . . .) and their respective composition in terms of the species participating in the reactions. Weighting factors must be read in the same order in which the thermodynamic data sets are read.

14	A6	1-6	AID(NS+1) (e.g., M1)	Name of first catalytic species
14a	F5.2	1-5	WF(1, 1)	Weighting factor of first species (for first catalytic species). Set weighting factor to zero for any reactant which does not contribute to the respective catalytic species.
	F5.2	6-10	WF(1, 2)	Weighting factor of second species contributing to first catalytic species.
		⋮		
	F5.2	75-80	WF(1, 16)	Weighting factor of sixteenth species contributing to first catalytic species.
14a	F5.2	1-5	WF(1, 17)	Weighting factor of seventeenth species contributing to first catalytic species, etc.
		⋮		
14	A6	1-6	AID(NS+2)	Name of second catalytic species.
14a	F5.2	1-5	WF(2, 1)	Weighting factor of first species contributing to second catalytic species, etc.
		⋮		
14	A6	1-6	AID(NS+NM)	Name of last catalytic species, etc.

*The same temperature points must be used for each species.

NOTES: 1. There are NM card no. 14s
2. There are as many card no. 14as as needed to account for NS species at 16 species/card

Card	Format	Column	Variable	Description
15	A6	1-6		Species A
		7		+ sign
	A6	8-13		Species B (or M)
	A6	14		+ sign
	6x	15-20		Blank or M
		21		= sign
	A6	22-27		Species C
		28		+ sign (if needed)
	A6	29-34		Species D (or M)
		35		+ sign (if needed)
	A6	36-41		Species E (or M)
		42-48		Blank
	I2	49-50		Reaction type, 1 to 12
	I1	51		Rate constant type, 1 to 5
	E8.2	52-59		A, pre-exponential factor (cm-particle-sec) units
	F5.2	60-64		N, temperature exponent
	F10.1	54-74		B, activation energy (cal/mole)
	F6.2	75-80		M, temperature exponent
16	8E10.6	1-10	PRINTX	Output print increment (cm)
		11-20	X	Initial X (usually 0.0 cm)
		21-30	DX	Step size (cm)
		31-40	XMAX	Terminal station (cm)
		41-50	XMIX	Mixing length (cm)

- - - - - - - - - - -Input Cards 17, 18, 19 and 20 only if IGAS = 1 - - - - - - - - - -

NOTE: Input 1 set of cards 17, 18 and 19 for each lasing specie (3 max)*+

17	8E10.6	1-10	WLM	– Molecular weight of the lasing species
		11-20	WE	System constants ω_e, $\omega_e x_e$, B_e, and α_e (1/cm) of the lasing molecule
		21-30	WEXE	
		31-40	BE	
		41-50	AE	
		51-60	RAS	Resonance broadening constant a* ($K^{\frac{1}{2}}$/cm-atm)
		61-70	RBS	Resonance broadening constant b* (K/cm-atm)
		71-80	SYMN	Symmetry number = 1.0 for diatomic molecules = 2.0 for CO_2

*Listed in same sequence as thermodynamic species.
+Data for typical lasing molecules may be found in Refs. 5 through 7.

Card	Format	Column	Variable	Description
18	8E10.6	1-10	AB	Curve-fit coefficients for the matrix elements of the dipole moment for the v=1 — v=0 transition of the lasing molecule.
		11-20	BB	
		21-30	CB	
		31-40	AV	
		41-50	BV	
19	20I4	1-4	JFIX(NV)	JFIX(1) Lower level rotational quantum numbers for all transitions (1, NV)*
		5-8		JFIX(2)
		etc		etc.
				If input as zero, the program will locally select all J-values based on the highest gain (J-shifting).

NOTE: The following card group specifies the collision broadening constants, a_j(j=1, NS), one for each species, in the same order in which the thermodynamic data sets are read (input only if LFLAG = 1).

20	8E10.6	1-10	RA(NS)	Collision broadening constant for each chemical species.
		11-20		
		etc.		

NOTE: Cards 21 and 21a contain the initial conditions for each stream.+ There is one set of cards 21 and 21a for each stream

21	8E10.6	1-10	P	Known pressure (torr)
		11-20	U	Known velocity (cm/sec)
		21-30	T	Known temperature (K)
		31-40	SIZ	Known stream size (cm)
		41-50	ALPHA(NS)	Species mole fractions** (species 1 to 4)
		51-60		
		61-70		
		71-80		
21a	8E10.6	1-10	ALPHA(NS)	Seventh species mole fraction, etc.
		etc.		

*For operation at fixed J-values.

**Listed in same sequence as thermodynamic tables.

+Stream 1 is the reacting/lasing stream.

Card	Format	Column	Variable	Description
22	I5		PPLOT	Number of parameters to be plotted.
23	16I5		PLOT	Input control flags for parameters to be plotted =1, power =2, pressure =3, velocity =4, temperature =5, density =xx6, species (where xx is the particular species)

NOTE: The order in which PLOT is input is arbitrary.

NOTE: Card 24 contains the coefficients defining the width of the lasing zone and is read only if ILASL=1. The width is given by a second order equation of the form:

$$ILASL = Q_0 + Q_1 x + Q_2 x^2$$

24	3E10.6	1-10	COEF(10)	Q_0
		11-20		Q_1
		21-30		Q_2

Appendix C

ONE-DIMENSIONAL LASER AND MIXING PROGRAM

(ODLAMP)

(Sample Cases)

C-1 Single Species Lasing (HF)

C-2 Multi-Species Lasing (DF and CO_2)

Appendix C

C-1 SAMPLE INPUT

```
ODLAMP TEST CASE - POWER ON - COMPARISON WITH 1-D LAMP AND RESALE
    2   24   12   50    1    5    6    0    0    0    0    1    1    1    0    1
 20.0
 0.95
 0.95
 0.0
 0.0
HF(0)    20.008    -65.14
     0.          6.957     29.084     -2.075      50.          6.957     29.084     -1.727
   100.          6.958     33.907     -1.379     150.          6.960     36.728     -1.031
   200.          6.961     38.731     -0.683     250.          6.962     40.284     -0.335
   300.          6.964     41.554      0.013     400.          6.967     43.557      0.710
   500.          6.970     45.112      1.406     600.          6.973     46.383      2.104
   700.          6.976     47.458      2.811     800.          6.981     48.390      3.499
   900.          6.986     49.213      4.197    1000.          6.992     49.949      4.896
  1200.          7.007     51.225      6.296    1400.          7.023     52.305      7.699
  1600.          7.041     53.245      9.105    1800.          7.061     54.076     10.516
  2000.          7.080     54.821     11.930    2200.          7.100     55.497     13.488
  2400.          7.120     56.115     14.770    2600.          7.140     56.685     16.196
  2800.          7.160     57.216     17.626    3000.          7.180     57.711     19.060
HF(1)    20.008    -53.813
     0.          6.957     29.084     -2.075      50.          6.957     29.084     -1.727
   100.          6.958     33.907     -1.379     150.          6.960     36.728     -1.031
   200.          6.961     38.731     -0.683     250.          6.962     40.284     -0.335
   300.          6.964     41.554      0.013     400.          6.967     43.557      0.710
   500.          6.970     45.112      1.406     600.          6.973     46.383      2.104
   700.          6.976     47.458      2.811     800.          6.981     48.390      3.499
   900.          6.986     49.213      4.197    1000.          6.992     49.949      4.896
  1200.          7.007     51.225      6.296    1400.          7.023     52.305      7.699
  1600.          7.041     53.245      9.105    1800.          7.061     54.076     10.516
  2000.          7.080     54.821     11.930    2200.          7.100     55.497     13.488
  2400.          7.120     56.115     14.770    2600.          7.140     56.685     16.196
  2800.          7.160     57.216     17.626    3000.          7.180     57.711     19.060
HF(2)    20.008    -42.978
     0.          6.957     29.084     -2.075      50.          6.957     29.084     -1.727
   100.          6.958     33.907     -1.379     150.          6.960     36.728     -1.031
   200.          6.961     38.731     -0.683     250.          6.962     40.284     -0.335
   300.          6.964     41.554      0.013     400.          6.967     43.557      0.710
   500.          6.970     45.112      1.406     600.          6.973     46.383      2.104
   700.          6.976     47.458      2.811     800.          6.981     48.390      3.499
   900.          6.986     49.213      4.197    1000.          6.992     49.949      4.896
  1200.          7.007     51.225      6.296    1400.          7.023     52.305      7.699
  1600.          7.041     53.245      9.105    1800.          7.061     54.076     10.516
  2000.          7.080     54.821     11.930    2200.          7.100     55.497     13.488
  2400.          7.120     56.115     14.770    2600.          7.140     56.685     16.196
  2800.          7.160     57.216     17.626    3000.          7.180     57.711     19.060
HF(3)    20.008    -32.622
     0.          6.957     29.084     -2.075      50.          6.957     29.084     -1.727
   100.          6.958     33.907     -1.379     150.          6.960     36.728     -1.031
   200.          6.961     38.731     -0.683     250.          6.962     40.284     -0.335
   300.          6.964     41.554      0.013     400.          6.967     43.557      0.710
   500.          6.970     45.112      1.406     600.          6.973     46.383      2.104
   700.          6.976     47.458      2.811     800.          6.981     48.390      3.499
   900.          6.986     49.213      4.197    1000.          6.992     49.949      4.896
  1200.          7.007     51.225      6.296    1400.          7.023     52.305      7.699
  1600.          7.041     53.245      9.105    1800.          7.061     54.076     10.516
  2000.          7.080     54.821     11.930    2200.          7.100     55.497     13.488
  2400.          7.120     56.115     14.770    2600.          7.140     56.685     16.196
```

2500.		7.160	57.216	17.626	3000.	7.180	57.711	19.060
HF(4)	20.008	-22.732						
0.		6.957	29.084	-2.075	50.	6.957	29.084	-1.727
100.		6.958	33.907	-1.379	150.	6.960	36.728	-1.031
200.		6.961	38.731	-0.683	250.	6.962	40.284	-0.335
300.		6.964	41.554	0.013	400.	6.967	43.557	0.710
500.		6.970	45.112	1.406	600.	6.973	46.383	2.104
700.		6.976	47.458	2.811	800.	6.981	48.390	3.499
900.		6.986	49.213	4.197	1000.	6.992	49.949	4.896
1200.		7.007	51.225	6.296	1400.	7.023	52.305	7.699
1600.		7.041	53.245	9.105	1800.	7.061	54.076	10.516
2000.		7.080	54.821	11.930	2200.	7.100	55.497	13.488
2400.		7.120	56.115	14.770	2600.	7.140	56.685	16.196
2800.		7.160	57.216	17.626	3000.	7.180	57.711	19.060
HF(5)	20.008	-13.299						
0.		6.957	29.084	-2.075	50.	6.957	29.084	-1.727
100.		6.958	33.907	-1.379	150.	6.960	36.728	-1.031
200.		6.961	38.731	-0.683	250.	6.962	40.284	-0.335
300.		6.964	41.554	0.013	400.	6.967	43.557	0.710
500.		6.970	45.112	1.406	600.	6.973	46.383	2.104
700.		6.976	47.458	2.811	800.	6.981	48.390	3.499
900.		6.986	49.213	4.197	1000.	6.992	49.949	4.896
1200.		7.007	51.225	6.296	1400.	7.023	52.305	7.699
1600.		7.041	53.245	9.105	1800.	7.061	54.076	10.516
2000.		7.080	54.821	11.930	2200.	7.100	55.497	13.488
2400.		7.120	56.115	14.770	2600.	7.140	56.685	16.196
2800.		7.160	57.216	17.626	3000.	7.180	57.711	19.060
HF(6)	20.008	-4.313						
0.		6.957	29.084	-2.075	50.	6.957	29.084	-1.727
100.		6.958	33.907	-1.379	150.	6.960	36.728	-1.031
200.		6.961	38.731	-0.683	250.	6.962	40.284	-0.335
300.		6.964	41.554	0.013	400.	6.967	43.557	0.710
500.		6.970	45.112	1.406	600.	6.973	46.383	2.104
700.		6.976	47.458	2.811	800.	6.981	48.390	3.499
900.		6.986	49.213	4.197	1000.	6.992	49.949	4.896
1200.		7.007	51.225	6.296	1400.	7.023	52.305	7.699
1600.		7.041	53.245	9.105	1800.	7.061	54.076	10.516
2000.		7.080	54.821	11.930	2200.	7.100	55.497	13.488
2400.		7.120	56.115	14.770	2600.	7.140	56.685	16.196
2800.		7.160	57.216	17.626	3000.	7.180	57.711	19.060
F	19.	18.34						
0.		5.068	29.481	-1.558	50.	5.068	29.481	-1.495
100.		5.068	32.116	-1.059	150.	5.325	34.201	-0.803
200.		5.403	35.746	-0.534	250.	5.430	36.960	-0.262
300.		5.436	37.951	0.010	400.	5.361	39.505	0.550
500.		5.282	40.693	1.082	600.	5.218	41.650	1.607
700.		5.169	42.45	2.126	800.	5.133	43.138	2.641
900.		5.105	43.741	3.153	1000.	5.083	44.277	3.663
1200.		5.052	45.201	4.676	1400.	5.032	45.978	5.684
1600.		5.018	46.649	6.689	1800.	5.009	47.24	7.692
2000.		5.001	47.767	8.693	2200.	4.996	48.244	9.692
2400.		4.992	48.678	10.691	2600.	4.988	49.078	11.689
2800.		4.986	49.447	12.687	3000.	4.984	49.791	13.683
F2	38.	0.						
0.		6.958	35.871	-2.110	50.	6.958	35.871	-1.762
100.		6.958	40.694	-1.414	150.	6.949	43.522	-1.066
200.		7.095	45.542	-0.714	250.	7.281	47.146	-0.356
300.		7.489	48.489	0.014	400.	7.883	50.699	0.763

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   500.          8.183     52.492     1.587    600.          8.399     54.004     2.417
   700.          8.554     55.311     3.255    800.          8.670     56.461     4.125
   900.          8.759     57.488     4.998   1000.          8.829     58.414     5.876
  1200.          8.935     60.034     7.655   1400.          9.012     61.417     9.450
  1600.          9.074     62.625    11.258   1800.          9.126     63.697    13.078
  2000.          9.172     64.661    14.908   2200.          9.214     65.537    16.747
  2400.          9.253     66.340    18.594   2600.          9.290     67.082    20.448
  2800.          9.325     67.772    22.529   3000.          9.360     68.417    24.179
H         1.008     52.102
     0.          4.968     19.382    -1.481     50.          4.968     19.382    -1.233
   100.          4.968     21.965    -0.984    150.          4.968     23.979    -0.736
   200.          4.968     25.408    -0.488    250.          4.968     26.517    -0.239
   300.          4.968     27.423     0.009    400.          4.968     28.852     0.506
   500.          4.968     29.961     1.003    600.          4.968     30.867     1.5
   700.          4.968     31.632     1.996    800.          4.968     32.296     2.493
   900.          4.968     32.881     2.990   1000.          4.968     33.404     3.487
  1200.          4.968     34.310     4.481   1400.          4.968     35.075     5.474
  1600.          4.968     35.739     6.468   1800.          4.968     36.325     7.461
  2000.          4.968     36.848     8.455   2200.          4.968     37.322     9.449
  2400.          4.968     37.754    10.442   2600.          4.968     38.156    11.436
  2800.          4.968     38.520    12.430   3000.          4.968     38.862    13.423
H2        2.016      0.
     0.          6.728     19.386    -1.980     50           6.728     19.386    -1.643
   100.          6.728     24.049    -1.307    150.          6.654     26.614    -0.993
   200.          6.560     28.515    -0.663    250.          6.706     29.995    -0.331
   300.          6.894     31.251     0.013    400.          6.975     33.247     0.707
   500.          6.993     34.806     1.406    600.          7.009     36.082     2.106
   700.          7.036     37.165     2.808    800.          7.087     38.107     3.514
   900.          7.148     38.946     4.226   1000.          7.219     39.702     4.944
  1200.          7.39      41.033     6.404   1400.          7.60      42.187     7.902
  1600.          7.823     43.217     9.446   1800.          8.016     44.15     11.03
  2000.          8.195     45.004    12.651   2200.          8.358     45.793    14.307
  2400.          8.506     46.527    15.993   2600.          8.639     47.213    17.708
  2800.          8.757     47.857    19.448   3000.          8.859     48.455    21.21
HE        4.003      0.
     0.          4.968     21.255    -1.481     50.          4.968     21.255    -1.233
   100.          4.968     24.698    -0.984    150.          4.968     26.128    -0.736
   200.          4.968     28.142    -0.488    250.          4.968     29.048    -0.239
   300.          4.968     30.156     0.009    400.          4.968     31.586     0.506
   500.          4.968     32.694     1.003    600.          4.968     33.600     1.500
   700.          4.968     34.366     1.996    800.          4.968     35.029     2.493
   900.          4.968     35.614     2.990   1000.          4.968     36.138     3.487
  1200.          4.968     37.044     4.481   1400.          4.968     37.809     5.474
  1600.          4.968     38.473     6.468   1800.          4.968     39.058     7.461
  2000.          4.968     39.581     8.455   2200.          4.968     40.055     9.449
  2400.          4.968     40.487    10.442   2600.          4.968     40.885    11.436
  2800.          4.968     41.253    12.430   3000.          4.968     41.596    13.423
M2
  1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0 20.0          1.0
M3
  1.0   1.0   1.0   1.0   1.0   1.0   1.0 18.0
M4
  1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0
M5
                                                1.0   1.0   1.0   3.0
M6
  1.0   1.0   1.0   1.0   1.0   1.0   1.0
H       +H       +M2      =H2      +M2                          22 2.76-30 1.00
```

```
F2      +M4
HF(0)  +M4
HF(1)  +M4
HF(2)  +M4
HF(3)  +M4
F       +H2
F       +H2
F       +H2
F       +H2
HF(4)  +H
HF(5)  +H
HF(6)  +H
H       +F2
H       +F2
H       +F2
H       +F2
H       +F2
H       +F2
H       +F2
HF(1)  +M3
HF(2)  +M3
HF(3)  +M3
HF(4)  +M3
HF(5)  +M3
HF(6)  +M3
HF(1)  +M6
HF(2)  +M6
HF(3)  +M6
HF(4)  +M6
HF(5)  +M6
HF(6)  +M6
HF(1)  +M5
HF(2)  +M5
HF(3)  +M5
HF(4)  +M5
HF(5)  +M5
HF(6)  +M5
HF(1)  +HF(1)
HF(2)  +HF(2)
HF(3)  +HF(3)
HF(4)  +HF(4)
HF(5)  +HF(5)
HF(1)  +HF(2)
HF(2)  +HF(3)
HF(3)  +HF(4)
HF(4)  +HF(5)
HF(1)  +HF(3)
HF(2)  +HF(4)
HF(3)  +HF(5)
```

```
=F      +F      +M4
=H      +F      +M4
=H      +F      +M4
=H      +F      +M4
=H      +F      +M4
=HF(0)  +H
=HF(1)  +H
=HF(2)  +H
=HF(3)  +H
=F      +H2
=F      +H2
=F      +H2
=HF(0)  +F
=HF(1)  +F
=HF(2)  +F
=HF(3)  +F
=HF(4)  +F
=HF(5)  +F
=HF(6)  +F
=HF(0)  +M3
=HF(1)  +M3
=HF(2)  +M3
=HF(3)  +M3
=HF(4)  +M3
=HF(5)  +M3
=HF(0)  +M6
=HF(1)  +M6
=HF(2)  +M6
=HF(3)  +M6
=HF(4)  +M6
=HF(5)  +M6
=HF(0)  +M5
=HF(1)  +M5
=HF(2)  +M5
=HF(3)  +M5
=HF(4)  +M5
=HF(5)  +M5
=HF(0)  +HF(2)
=HF(1)  +HF(3)
=HF(2)  +HF(4)
=HF(3)  +HF(5)
=HF(4)  +HF(6)
=HF(0)  +HF(3)
=HF(1)  +HF(4)
=HF(2)  +HF(5)
=HF(3)  +HF(6)
=HF(0)  +HF(4)
=HF(1)  +HF(5)
=HF(2)  +HF(6)
```

```
55 8.30-11        - 35300.0
54 2.0 -05 1.00  -135800.0
54 2.0 -05 1.00  -135800.0
54 2.0 -05 1.00  -135800.0
54 2.0 -05 1.00  -135800.0
13 1.5 -11        -   1600.0
13 3.0 -11        -   1600.0
13 1.5 -10        -   1600.0
13 7.5 -11        -   1600.0
12 1.66-12-0.67
12 1.66-12-0.67
12 1.66-12-0.67
13 1.0 -11        -   2400.0
13 1.0 -11        -   2400.0
13 1.5 -11        -   2400.0
13 2.67-11        -   2400.0
13 3.33-11        -   2400.0
13 5.5 -11        -   2400.0
13 5.0 -11        -   2400.0
62 8.3 -17-1.30
62 1.66-16-1.30
62 2.49-16-1.30
62 3.32-16-1.30
62 4.15-16-1.30
62 4.98-16-1.30
62 1.66-08 1.43
62 3.32-08 1.43
62 4.98-08 1.43
62 6.64-08 1.43
62 8.3 -08 1.43
62 9.96-08 1.43
62 2.16-26-3.6
62 4.32-26-3.6
62 6.48-26-3.6
62 8.64-26-3.6
62 1.08-25-3.6
62 1.3 -25-3.6
12 6.64-19-2.2
12 6.64-19-2.2
12 6.64-19-2.2
12 6.64-19-2.2
12 6.64-19-2.2
12 2.0 -21-2.8
12 2.0 -21-2.8
12 2.0 -21-2.8
12 2.0 -21-2.8
12 1.0 -25-3.9
12 1.0 -25-3.9
12 1.0 -25-3.9
```

```
.25          0.0          .01524      3.0
20.008       4140.0       90.0        20.95       0.796     1.74      252.0     1.0
0.97637      0.0506       0.00103     -0.05       1.05
  0   0      0   0   0    0
20.0         5.58    E5   500.0       0.227034    0.0       0.0       0.0       0.0
0.0          0.0          0.0         0.1         0.01      0.0       0.39      0.5
30.0
```

C-1 SAMPLE CALCULATION

ODLAMP TEST CASE - POWER ON - COMPARISON WITH 1-D LAMP AND RESALE

THE KNOWN PARAMETER FOR THIS CASE IS PRESS.

24 12 50 1 5 6 3 3 3 3 1 1 1 3 1 1

	REACTIONS BEING CONSIDERED	KR=A*EXP(B/RT**M)/T**N	A	N	B	M	R-TYPE	K-TYPE
1	M + M + M2 = M2 + M2		1.0J2E+18	1.0	-0.0	-0.0	2	2
2	F2 + M4 = F + F + M4		5.001E+13	-0.0	-35300.0	-0.0	5	3
3	HF(3) + M4 = H + F + M4		1.205E+19	1.0	-135800.0	-0.0	5	4
4	HF(1) + M4 = H + F + M4		1.205E+19	1.0	-135800.0	-0.0	5	4
5	HF(2) + M4 = H + F + M4		1.205E+19	1.0	-135800.0	-0.0	5	4
6	HF(3) + M4 = H + F + M4		1.205E+19	1.0	-135800.0	-0.0	5	4
7	F + H2 = HF(3) + H		9.038E+12	-0.0	-1600.0	-0.0	1	3
8	F + H2 = HF(1) + H		1.808E+13	-0.0	-1600.0	-0.0	1	3
9	F + H2 = HF(2) + H		9.037E+13	-0.0	-1600.0	-0.0	1	3
10	F + H2 = HF(3) + H		4.519E+13	-0.0	-1600.0	-0.0	1	3
11	HF(4) + H = F + H2		1.000E+12	-.7	-0.0	-0.0	1	2
12	HF(5) + H = F + H2		1.000E+12	-.7	-0.0	-0.0	1	2
13	HF(6) + H = F + H2		1.000E+12	-.7	-0.0	-0.0	1	2
14	M + F2 = HF(3) + F		6.025E+12	-0.0	-2400.0	-0.0	1	3
15	M + F2 = HF(1) + F		6.025E+12	-0.0	-2400.0	-0.0	1	3
16	M + F2 = HF(2) + F		9.038E+12	-0.0	-2400.0	-0.0	1	3
17	M + F2 = HF(3) + F		1.619E+13	-0.0	-2400.0	-0.0	1	3
18	M + F2 = HF(4) + F		2.006E+13	-0.0	-2400.0	-0.0	1	3
19	M + F2 = HF(5) + F		3.314E+13	-0.0	-2400.0	-0.0	1	3
20	M + F2 = HF(6) + F		3.013E+13	-0.0	-2400.0	-0.0	1	3
21	HF(1) + M3 = HF(3) + M3		5.001E+07	-1.3	-0.0	-0.0	6	2
22	HF(2) + M3 = HF(1) + M3		1.000E+08	-1.3	-0.0	-0.0	6	2
23	HF(3) + M3 = HF(2) + M3		1.500E+08	-1.3	-0.0	-0.0	6	2
24	HF(4) + M3 = HF(3) + M3		2.000E+08	-1.3	-0.0	-0.0	6	2
25	HF(5) + M3 = HF(4) + M3		2.500E+08	-1.3	-0.0	-0.0	6	2
26	HF(6) + M3 = HF(5) + M3		3.000E+08	-1.3	-0.0	-0.0	6	2
27	HF(1) + M6 = HF(3) + M6		1.000E+16	1.4	-0.0	-0.0	6	2
28	HF(2) + M6 = HF(1) + M6		2.000E+16	1.4	-0.0	-0.0	6	2
29	HF(3) + M6 = HF(2) + M6		3.000E+16	1.4	-0.0	-0.0	6	2
30	HF(4) + M6 = HF(3) + M6		4.001E+16	1.4	-0.0	-0.0	6	2
31	HF(5) + M6 = HF(4) + M6		5.001E+16	1.4	-0.0	-0.0	6	2
32	HF(6) + M6 = HF(5) + M6		6.001E+16	1.4	-0.0	-0.0	6	2
33	HF(1) + M5 = HF(3) + M5		1.301E-02	-3.6	-0.0	-0.0	6	2
34	HF(2) + M5 = HF(1) + M5		2.603E-02	-3.6	-0.0	-0.0	6	2
35	HF(3) + M5 = HF(2) + M5		3.904E-02	-3.6	-0.0	-0.0	6	2
36	HF(4) + M5 = HF(3) + M5		5.206E-02	-3.6	-0.0	-0.0	6	2
37	HF(5) + M5 = HF(4) + M5		6.507E-02	-3.6	-0.0	-0.0	6	2
38	HF(6) + M5 = HF(5) + M5		7.833E-02	-3.6	-0.0	-0.0	6	2
39	HF(1) + HF(1) = HF(3) + HF(2)		4.001E+05	-2.2	-0.0	-0.0	1	2
40	HF(2) + HF(2) = HF(1) + HF(3)		4.001E+05	-2.2	-0.0	-0.0	1	2
41	HF(3) + HF(3) = HF(2) + HF(4)		4.001E+05	-2.2	-0.0	-0.0	1	2
42	HF(4) + HF(4) = HF(3) + HF(5)		4.001E+05	-2.2	-0.0	-0.0	1	2
43	HF(5) + HF(5) = HF(4) + HF(6)		4.001E+05	-2.2	-0.0	-0.0	1	2
44	HF(1) + HF(2) = HF(3) + HF(3)		1.205E+03	-2.8	-0.0	-0.0	1	2
45	HF(2) + HF(3) = HF(1) + HF(4)		1.205E+03	-2.8	-0.0	-0.0	1	2
46	HF(3) + HF(4) = HF(2) + HF(5)		1.205E+03	-2.8	-0.0	-0.0	1	2
47	HF(4) + HF(5) = HF(3) + HF(6)		1.205E+03	-2.8	-0.0	-0.0	1	2
48	HF(1) + HF(3) = HF(3) + HF(4)		6.025E-02	-3.9	-0.0	-0.0	1	2
49	HF(2) + HF(4) = HF(1) + HF(5)		6.025E-02	-3.9	-0.0	-0.0	1	2
50	HF(3) + HF(5) = HF(2) + HF(6)		6.025E-02	-3.9	-0.0	-0.0	1	2

CATALYTIC SPECIES BEING CONSIDERED

```
M2     = 1.00 MF(0) , 1.00 MF(1) , 1.00 MF(2) , 1.00 MF(3) , 1.00 MF(4) , 1.00 MF(5) , 1.00 MF(6) ,
         1.00 F     , 1.00 F2    ,0.00 H     ,-0.00 H2    , 1.00 HE    ,

M3     = 1.00 MF(0) , 1.00 MF(1) , 1.00 MF(2) , 1.00 MF(3) , 1.00 MF(4) , 1.00 MF(5) , 1.00 MF(6) ,
        18.00 F     ,-0.00 F2    ,-0.00 H     ,-0.00 H2    ,-0.00 HE    ,

M4     = 1.00 MF(0) , 1.00 MF(1) , 1.00 MF(2) , 1.00 MF(3) , 1.00 MF(4) , 1.00 MF(5) , 1.00 MF(6) ,
         1.00 F     , 1.00 F2    , 1.00 H     , 1.00 H2    , 1.00 HE    ,

M5     =-0.00 MF(0) ,-0.00 MF(1) ,-0.00 MF(2) ,-0.00 MF(3) ,-0.00 MF(4) ,-0.00 MF(5) ,-0.00 MF(6) ,
        -0.00 F     , 1.00 F2    , 1.00 H     , 1.00 H2    , 3.00 HE    ,

M6     = 1.00 MF(0) , 1.00 MF(1) , 1.00 MF(2) , 1.00 MF(3) , 1.00 MF(4) , 1.00 MF(5) , 1.00 MF(6) ,
        -0.00 F     ,-0.00 F2    ,-0.00 H     ,-0.00 H2    ,-0.00 HE    ,
```

```
THE KNOWN DATA COEFFICIENTS ARE
    1    .20000E+02  -0.          -0.          -0.          -0.          -0.          -0.
    2    .95000E+00  -0.          -0.          -0.          -0.          -0.          -0.
    3    .95000E+00  -0.          -0.          -0.          -0.          -0.          -0.
    4    0.          -0.          -0.          -0.          -0.          -0.          -0.
    5    0.          -0.          -0.          -0.          -0.          -0.          -0.

PRINTX=  .25000E+00 X0= 0.          DX=  .15240E-01 XMAX=  .30000E+01

WLM=  .20000E+02 WE=  .41400E+04 WEXE=  .90000E+02 BE=  .20950E+02 AE=  .79600E+00 RAS=  .17400E+01 RBS=  .25200E+03 SYMN=  .10000E+01

 AB=  .97537E+00 BB=  .50600E-01 CB=  .10300E-02 AV= -.50000E-01 BV=  .13500E+01

LOWER LEVEL ROTATIONAL QUANTUM NUMBERS

    0    0    0    0    0    0

THE COLLISION BROADENING CONSTANTS ARE-

    .17400E+01    .17400E+01    .17400E+01    .17400E+01    .17400E+01    .17400E+01    .17400E+01    .86500E+00    .86500E+00

    .86500E+00    .86500E+00    .86500E+00
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ODLAMP TEST CASE - POWER ON - COMPARISON WITH 1-D LAMP AND RESALE

X (CM) .55511E-16 AREA (CM**2/CM) .22703E+00 DELTAX (CM) .15240E-01 MDOT (G/SEC/CM) .41186E+00

STREAM DATA

S	U(CM/SEC)	P(TORR)	T(DEG K)	H(CAL/G)	RHO(G/CC)	R(CM)	MOL. WT.	M(G/SEC/CM)	CP(CAL/G/K)
1	.55800E+06	.20000E+02	.50000E+03	.59354E+03	.32510E-05	.22703E+00	.50677E+01	.41186E+00	.11487E+01

SPECIES MOLE FRACTIONS

1

HF(0)	.50677E-29	HF(1)	.50677E-29	HF(2)	.50677E-29	HF(3)	.50677E-29	HF(4)	.50677E-29	HF(5)	.50677E-29
HF(6)	.50677E-29	F	.10000E+00	F2	.10000E-01	H	.50677E-29	H2	.39600E+00	HE	.50000E+00

ODLAMP TEST CASE - POWER ON - COMPARISON WITH 1-D LAMP AND RESALE

X (CM) .55511E-16 AREA (CM**2/CM) .22703E+00 DELTAX (CM) .15240E-01 MDOT (G/SEC/CM) .41186E+00

MULTI-LEVEL CL-INFORMATION

	ALFA(1/CM)	LENGTH(CM)	R1	R2	A1	A2	T1	T2
	1.709776E-03	3.000000E+01	.950000	.950000	0.000000	0.000000	.050000	.050000

K	IL	J	AVGN (1/CM)	LAMBDA (CM)	I(INTRNL) (W/SQCM)	I(OUT) (W/SQCM)	I(USEFUL) (W/SQCM)	PWR(OUT)/H (KW/CM)	PWR(USF)/H (KW/CM)
1	0	5	1.102455E-28	2.674827E-04					
2	0	5	2.201710E-28	2.663854E-04					
3	0	5	3.231390E-28	2.945959E-04					
4	0	5	4.181238E-28	3.103239E-04					
5	0	5	5.040802E-28	3.278259E-04					
6	0	5	5.799532E-28	3.474201E-04					

ILS= 0 IFLAG= 2 X= .55511E-15 RAOT=

1	0	5	1.102455E-28	0.	9.128241E-29	1.085700E-28
2	0	5	2.201710E-28	0.	1.871682E-28	2.121972E-28
3	0	5	3.231390E-28	0.	2.820988E-28	3.044259E-28
4	0	5	4.181238E-28	0.	3.749442E-28	3.848791E-28
5	0	5	5.040802E-28	0.	4.544517E-28	4.531821E-28
6	0	5	5.799532E-28	0.	5.492461E-28	5.089707E-28

TRANSITION NO. 2 GAIN ABOVE THRESHOLD

X = 1.524000E-02 AVGN = 8.821242E-01 JMAX = 4 RETURN TO PREVIOUS X

TRANSITION NO. 2 GAIN ABOVE THRESHOLD

X = 2.953892E-05 AVGN = 2.442063E-03 JMAX = 4 RETURN TO PREVIOUS X

TRANSITION NO. 2 GAIN ABOVE THRESHOLD

X = 2.068127E-05 AVGN = 1.710191E-03 JMAX = 4 RETURN TO PREVIOUS X

TRANSITION NO. 2 *** THRESHOLD *** X = 2.067525E-05 (FT)

ODLAMP TEST CASE - POWER ON - COMPARISON WITH 1-D LAMP AND RESALE

X (CM) .55511E-16

K	1	RAI	0.	RAO	0.	RAJ	0.	PWRO	0.	PWRU	0.
K	2	RAI	0.	RAO	0.	RAJ	0.	PWRO	0.	PWRU	0.
K	3	RAI	0.	RAO	0.	RAJ	0.	PWRO	0.	PWRU	0.
K	4	RAI	0.	RAO	0.	RAJ	0.	PWRO	0.	PWRU	0.
K	5	RAI	0.	RAO	0.	RAJ	0.	PWRO	0.	PWRU	0.
K	6	RAI	0.	RAO	0.	RAJ	0.	PWRO	0.	PWRU	0.

RAIT 0. RAOT 0. RAUT 0. TPWRO 0. TPWRU 0. STPWRO 0. STPWRU 0.

ODLAMP TEST CASE - POWER ON - COMPARISON WITH 1-D LAMP AND RESALE

X (CM) .20676E-04 AREA (CM**2/CM) .22705E+00 DELTAX (CM) .20676E-04 MDOT (G/SEC/CM) .41186E+00

STREAM DATA

S	U(CM/SEC)	P(TORR)	T(DEG K)	H(CAL/G)	RHO(G/CC)	R(CM)	MOL. WT.	M(G/SEC/CM)	CP(CAL/G/K)
1	.55809E+06	.20000E+02	.50005E+03	.59354E+03	.32507E-05	.22705E+00	.50677E+01	.41186E+00	.[illegible]E+01

SPECIES MOLE FRACTIONS

1												
HF(0)	.16720E-15	HF(1)	.33441E-05	HF(2)	.16719E-04	HF(3)	.83596E-05	HF(4)	.79384E-03	HF(5)	.21204E-11
HF(6)	.19222E-13	F	.99970E-01	F2	.10000E-01	H	.33096E-04	H2	.38997E+00	HE	.50000E+00

DDLAMP TEST CASE - POWER ON - COMPARISON WITH 1-D LAMP AND RESALE

X (CM) .20676E-04 AREA (CM**2/CM) .22705E+00 DELTAX (CM) .20676E-04 MDOT (G/SEC/CM) .41195E+00

MULTI-LEVEL CL-INFORMATION

ALFA(1/CM)	LENGTH(CM)	R1	R2	A1	A2	T1	T2
1.709776E-03	3.000000E+01	.950000	.950000	0.000000	0.000000	.050000	.050000

K	IL	J	AVGN (1/CM)	LAMBDA (CM)	I(INTRNL) (W/SQCM)	I(OUT) (W/SQCM)	I(USEFUL) (W/SQCM)	PWR(OUT)/H (KW/CM)	PWR(USF)/H (KW/CM)
1	1	4	1.328902E-04	2.541268E-04					
2	1	4	1.709777E-03	2.760243E-04					
3	1	8	8.261813E-05	3.074970E-04					
4	0	28	-2.521593E-20	5.552348E-04					
5	1	25	1.107150E-20	5.279831E-04					
6	1	5	1.824831E-09	3.474201E-04					

ILS= 1 IFLAG= 2 X= .20676E-04 RADT=

1	0	4	1.328902E-04	1.102459E-28	1.172036E-04	1.247289E-04
2	1	4	1.709777E-03	2.201710E-28	1.477048E-03	1.658904E-03
3	0	8	8.261813E-05	3.231390E-28	6.101781E-05	7.175887E-05
4	0	28	-2.521593E-20	4.181238E-28	0.	-4.395612E-19
5	0	25	1.107150E-20	5.040802E-28	2.040387E-21	-3.641583E-21
6	0	5	1.824831E-09	5.799532E-28	1.816873E-09	1.470457E-09

J SHIFT(1)ENCOUNTERED ON TRANSITION NO. 2, X= 1.737762E-04
1.707544E-03 2.185541E-03 2.081920E-03
1.658904E-03 1.709777E-03 1.477048E-03
RETURN TO X= 2.067625E-05 DX= 1.642398E-06

J-SHIFT(1)ENCOUNTERED ON TRANSITION NO. 2, X= 7.073714E-05
1.709534E-03 1.710826E-03 1.420514E-03
1.658904E-03 1.709777E-03 1.477048E-03
RETURN TO X= 2.067625E-05 DX= 1.635063E-06

J-SHIFT(1)ENCOUNTERED ON TRANSITION NO. 2, X= 7.051358E-05

X= 7.051358E-05 (CM)EQUAL GAIN FOR ADJACENT J-LEVELS ON TRANSITION NO. 2

ODLAMP TEST CASE - POWER ON - COMPARISON WITH 1-D LAMP AND RESALE

X (CM) .20676E-04

K 1 RAI 0. RAO 0. RAU 0. PWRO 0. PWRU 0.

K 2 RAI .38748E+07 RAO .19875E+06 RAU .19875E+06 PWRO 0. PWRU 0.

K 3 RAI 0. RAO 0. RAJ 0. PWRO 0. PWRU 0.

K 4 RAI 0. RAO 0. RAU 0. PWRO 0. PWRU 0.

K 5 RAI 0. RAO 0. RAU 0. PWRO 0. PWRU 0.

K 6 RAI 0. RAO 0. RAU 0. PWRO 0. PWRU 0.

RAIT .38748E+07 RAOT .19875E+06 RAUT .19875E+06 TPWRO 0. TPWRO 0. STPWRO 0. STPWRU 0.

ODLAMP TEST CASE - POWER ON - COMPARISON WITH 1-D LAMP AND RESALE

X (CM) .70514E-04 AREA (CM**2/CM) .22711E+00 DELTAX (CM) .49837E-04 MDOT (G/SEC/CM) .41186E+00

STREAM DATA

S	U(CM/SEC)	P(TORR)	T(DEG K)	H(CAL/G)	RHO(G/CC)	R(CM)	MOL. WT.	M(G/SEC/CM)	CP(CAL/G/K)
1	.55800E+06	.20000E+02	.50016E+03	.59350E+03	.32500E-05	.22711E+00	.50677E+01	.41186E+00	.11487E+01

SPECIES MOLE FRACTIONS

1

HF(0)	.56988E-05	HF(1)	.32744E-04	HF(2)	.35639E-04	HF(3)	.28491E-04	HF(4)	.27817E-08	HF(5)	.19508E-09
HF(6)	.17715E-09	F	.99897E-01	F2	.10000E-01	H	.13258E-03	H2	.38990E+00	HE	.50000E+00

ODLAMP TEST CASE - POWER ON - COMPARISON WITH 1-D LAMP AND RESALE

X (CM) .70514E-04 AREA (CM**2/CM) .22711E+00 DELTAX (CM) .49837E-04 MDOT (G/SEC/CM) .41186E+00

MULTI-LEVEL CL-INFORMATION

ALFA(1/CM)	LENGTH(CM)	R1	R2	A1	A2	T1	T2
1.709776E-03	3.000000E+01	.950000	.950000	0.000000	0.000000	.050000	.050000

K	IL	J	AVGN (1/CM)	LAMBDA (CM)	I(INTRNL) (W/SQCM)	I(OUT) (W/SQCM)	I(USEFUL) (W/SQCM)	PWR(OUT)/H (KW/CM)	PWR(USF)/H (KW/CM)
1	0	4	1.691105E-03	2.641288E-04					
2	1	5	1.709779E-03	2.803854E-04					
3	0	5	1.191766E-03	2.945959E-04					
4	0	28	-8.669058E-20	5.552348E-04					
5	0	20	2.015734E-15	4.458712E-04					
6	0	5	1.686842E-08	3.474201E-04					

ILS= 1 IFLAG= 2 X= .70514E-04 RADT=

1	0	4	1.691105E-03	1.328902E-04	1.430984E-03	1.557904E-03
2	1	5	1.709779E-03	1.709777E-03	1.419065E-03	1.709537E-03
3	0	5	1.191766E-03	8.261813E-05	1.177019E-03	8.902239E-04
4	0	28	-8.669058E-20	-2.521593E-20	0.	-1.510270E-18
5	0	20	2.015734E-15	1.107159E-20	6.452148E-16	-1.771443E-15
6	0	5	1.686842E-08	1.824831E-09	1.577953E-08	1.351684E-08

TRANSITION NO. 1 GAIN ABOVE THRESHOLD

X = 2.229136E-04 AVGN = 6.699408E-03 JMAX = 4 RETURN TO PREVIOUS X

TRANSITION NO. 1 GAIN ABOVE THRESHOLD

X = 7.107947E-05 AVGN = 1.709951E-03 JMAX = 4 RETURN TO PREVIOUS X

TRANSITION NO. 1 *** THRESHOLD *** X = 7.107947E-05 (FT)

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                    ODLAMP TEST CASE - POWER ON - COMPARISON WITH 1-D LAMP AND RESALE

X (CM)     .70514E-04
K       1 RAI  0.          RAO  0.          RAJ  0.          PWRO  0.          PWRU  0.
K       2 RAI   .40930E+07 RAO   .20994E+06 RAU   .20994E+06 PWRO   .11564E-03 PWRU   .11564E-03
K       3 RAI  0.          RAO  0.          RAJ  0.          PWRO  0.          PWRU  0.
K       4 RAI  0.          RAO  0.          RAJ  0.          PWRO  0.          PWRU  0.
K       5 RAI  0.          RAO  0.          RAJ  0.          PWRO  0.          PWRU  0.
K       6 RAI  0.          RAO  0.          RAU  0.          PWRO  0.          PWRU  0.
 RAIT   .40930E+07 RAOT   .20994E+06 RAUT   .20994E+06 TPWRO   .11564E-03 TPWRO   .11564E-03 STPWRO   .21255E-05 STPWRU   .21255E-05
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C-2 SAMPLE INPUT

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MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS
    2   24   18   60    1    9    4    1    0    0    0    2    1    1          1
 20.0
 20.0
 .077113
 0.99
 0.957
 0.01
 0.01
DF(0)    21.015    -65.850
     0.          6.957     30.498     -2.075     50.          6.957     30.498     -1.727
   100.          6.958     35.321     -1.379    150.          6.960     38.142     -1.031
   200.          6.961     40.145     -0.683    250.          6.962     41.698     -0.335
   300.          6.964     42.967      0.013    400.          6.967     44.971      0.710
   500.          6.970     46.526      1.407    600.          6.975     47.797      2.104
   700.          6.980     48.873      2.802    800.          6.987     49.805      3.500
   900.          6.994     50.629      4.199   1000.          7.002     51.366      4.899
  1200.          7.020     52.644      6.301   1400.          7.039     53.728      7.707
  1600.          7.059     54.669      9.117   1800.          7.079     55.501     10.530
  2000.          7.098     56.248     11.948   2200.          7.117     56.926     13.370
  2400.          7.137     57.546     14.795   2600.          7.155     58.118     16.224
  2800.          7.174     58.649     17.657   3000.          7.192     59.144     19.094
DF(1)    21.015    -57.54
     0.          6.957     30.498     -2.075     50.          6.957     30.498     -1.727
   100.          6.958     35.321     -1.379    150.          6.960     38.142     -1.031
   200.          6.961     40.145     -0.683    250.          6.962     41.698     -0.335
   300.          6.964     42.967      0.013    400.          6.967     44.971      0.710
   500.          6.970     46.526      1.407    600.          6.975     47.797      2.104
   700.          6.980     48.873      2.802    800.          6.987     49.805      3.500
   900.          6.994     50.629      4.199   1000.          7.002     51.366      4.899
  1200.          7.020     52.644      6.301   1400.          7.039     53.728      7.707
  1600.          7.059     54.669      9.117   1800.          7.079     55.501     10.530
  2000.          7.098     56.248     11.948   2200.          7.117     56.926     13.370
  2400.          7.137     57.546     14.795   2600.          7.155     58.118     16.224
  2800.          7.174     58.649     17.657   3000.          7.192     59.144     19.094
DF(2)    21.015    -49.49
     0.          6.957     30.498     -2.075     50.          6.957     30.498     -1.727
   100.          6.958     35.321     -1.379    150.          6.960     38.142     -1.031
   200.          6.961     40.145     -0.683    250.          6.962     41.698     -0.335
   300.          6.964     42.967      0.013    400.          6.967     44.971      0.710
   500.          6.970     46.526      1.407    600.          6.975     47.797      2.104
   700.          6.980     48.873      2.802    800.          6.987     49.805      3.500
   900.          6.994     50.629      4.199   1000.          7.002     51.366      4.899
  1200.          7.020     52.644      6.301   1400.          7.039     53.728      7.707
  1600.          7.059     54.669      9.117   1800.          7.079     55.501     10.530
  2000.          7.098     56.248     11.948   2200.          7.117     56.926     13.370
  2400.          7.137     57.546     14.795   2600.          7.155     58.118     16.224
  2800.          7.174     58.649     17.657   3000.          7.192     59.144     19.094
DF(3)    21.015    -41.70
     0.          6.957     30.498     -2.075     50.          6.957     30.498     -1.727
   100.          6.958     35.321     -1.379    150.          6.960     38.142     -1.031
   200.          6.961     40.145     -0.683    250.          6.962     41.698     -0.335
   300.          6.964     42.967      0.013    400.          6.967     44.971      0.710
```

1500.		0.970	52.626	1.487	600.	0.975	47.797	2.104
1700.		0.980	48.873	2.802	800.	0.987	49.803	3.500
1900.		0.994	50.629	4.199	1000.	7.002	51.366	4.899
2100.		1.020	52.644	5.601	1200.	7.039	53.728	7.707
2300.		1.059	54.669	7.117	1400.	7.079	55.901	10.530
2500.		1.096	56.248	11.946	2200.	7.117	58.926	13.370
2700.		1.131	57.548	14.795	2600.	7.155	60.118	16.224
2900.		1.174	58.649	17.657	3000.	7.192	59.144	19.094
DF(4)	21.015	-34.15						
0.		0.957	50.496	-2.078	0.	0.957	50.496	-1.727
100.		0.959	48.421	-1.377	150.	0.960	48.142	-1.031
200.		0.961	46.145	-0.663	250.	0.962	41.696	-0.333
300.		0.964	42.967	0.013	400.	0.967	44.971	0.710
500.		0.970	45.526	1.407	600.	0.975	47.797	2.104
700.		0.980	48.873	2.802	800.	0.987	49.803	3.500
900.		0.994	50.629	4.199	1000.	7.002	51.366	4.899
1200.		1.020	52.644	5.601	1400.	7.039	53.728	7.707
1600.		1.059	54.669	7.117	1800.	7.079	55.901	10.530
2000.		1.096	56.248	11.946	2200.	7.117	58.926	13.370
2400.		1.131	57.548	14.795	2600.	7.155	60.118	16.224
2800.		1.174	58.649	17.657	3000.	7.192	59.144	19.094
C02100	44.01	-90.081						
0.		0.955	37.932	-2.074	50.	0.955	37.932	-1.725
100.		0.955	42.753	-1.378	150.	0.955	45.574	-1.030
200.		0.955	47.575	-0.682	250.	0.955	49.127	-0.334
300.		0.955	50.395	0.013	400.	0.955	52.396	0.709
500.		0.955	53.948	1.404	600.	0.955	55.218	2.100
700.		0.955	56.288	2.796	800.	0.955	57.217	3.491
900.		0.955	58.036	4.187	1000.	0.955	58.769	4.882
1200.		0.955	60.037	6.273	1400.	0.955	61.109	7.664
1600.		0.955	62.038	9.055	1800.	0.955	62.857	10.446
2000.		0.955	63.590	11.838	2200.	0.955	64.253	13.229
2400.		0.955	64.858	14.620	2600.	0.955	65.413	16.011
2800.		0.955	65.930	17.402	3000.	0.955	66.410	18.793
C02001	44.01	-87.331						
0.		0.955	37.932	-2.074	50.	0.955	37.932	-1.725
100.		0.955	42.753	-1.378	150.	0.955	45.574	-1.030
200.		0.955	47.575	-0.682	250.	0.955	49.127	-0.334
300.		0.955	50.395	0.013	400.	0.955	52.396	0.709
500.		0.955	53.948	1.404	600.	0.955	55.218	2.100
700.		0.955	56.288	2.796	800.	0.955	57.217	3.491
900.		0.955	58.036	4.187	1000.	0.955	58.769	4.882
1200.		0.955	60.037	6.273	1400.	0.955	61.109	7.664
1600.		0.955	62.038	9.055	1800.	0.955	62.857	10.446
2000.		0.955	63.590	11.838	2200.	0.955	64.253	13.229
2400.		0.955	64.858	14.620	2600.	0.955	65.413	16.011
2800.		0.955	65.930	17.402	3000.	0.955	66.410	18.793
O2	4.03	0.						
0.		1.249	28.932	-2.048	50.	1.249	28.932	-1.720
100.		1.249	28.932	-1.351	150.	1.112	29.384	-1.030
200.		0.980	31.030	-0.665	250.	0.979	33.251	-0.336
300.		0.978	34.665	0.013	400.	0.989	36.672	0.710
500.		1.018	38.235	1.411	600.	1.079	39.519	2.116
700.		1.172	40.617	2.829	800.	1.297	41.532	3.551
900.		1.429	42.450	4.288	1000.	1.561	43.239	5.037
1200.		1.813	44.041	6.578	1400.	2.055	45.063	8.162
1600.		2.277	46.954	9.797	1800.	2.450	47.939	11.470
2000.		3.691	48.837	13.174	2200.	3.732	49.804	14.909

2400.		8.940	36.429	13.666	2400.	8.951	31.141	18.447
2500.		9.041	31.367	20.244	3000.	9.117	32.434	22.052
PZ	38.	0.						
0.		8.997	37.077	-2.11	50.	8.959	37.077	-2.023
100.		8.999	40.695	-1.415	150.	8.951	43.526	-1.066
200.		7.098	45.544	-0.715	250.	7.289	47.145	-0.350
300.		7.498	48.493	0.014	400.	7.900	50.707	0.784
500.		8.297	52.509	1.391	600.	8.429	54.022	2.423
700.		8.591	55.334	2.774	800.	8.713	56.469	4.14
900.		8.838	57.521	3.918	1000.	8.885	58.455	5.901
1200.		9.093	60.384	7.698	1400.	9.092	61.479	9.500
1600.		9.189	62.898	11.320	1800.	9.229	63.781	13.166
2000.		9.287	64.757	15.017	2200.	9.341	65.644	16.880
2400.		9.391	66.459	18.753	2600.	9.440	67.213	20.637
2800.		9.488	67.914	22.529	3000.	9.534	68.570	24.432
MF	28.000	-69.14						
0.		8.962	29.076	-2.055	50.	8.962	29.076	-1.708
100.		8.962	33.902	-1.360	150.	8.962	36.725	-1.021
200.		8.962	38.728	-0.663	250.	8.963	40.282	-0.335
300.		8.964	41.552	0.013	400.	8.967	43.555	0.709
500.		8.972	45.110	1.406	600.	8.986	46.382	2.104
700.		9.013	47.462	2.804	800.	9.063	48.402	3.508
900.		9.124	49.238	4.217	1000.	9.210	49.991	4.934
1200.		9.402	51.322	6.395	1400.	9.603	52.460	7.896
1600.		9.500	53.507	9.437	1800.	9.977	54.436	11.015
2000.		8.132	55.286	12.665	2200.	8.265	56.067	14.266
2400.		8.389	56.791	15.933	2600.	8.493	57.467	17.621
2800.		8.584	58.100	19.329	3000.	8.664	58.695	21.054
CO2300	44.01	-94.351						
0.		8.955	37.932	-2.074	50.	8.955	37.932	-1.725
100.		8.955	42.753	-1.378	150.	8.955	45.574	-1.030
200.		8.955	47.575	-0.682	250.	8.955	49.127	-0.334
300.		8.955	50.395	0.013	400.	8.955	52.390	0.709
500.		8.955	53.948	1.404	600.	8.955	55.216	2.100
700.		8.955	56.268	2.796	800.	8.955	57.217	3.491
900.		8.955	58.036	4.187	1000.	8.955	58.769	4.882
1200.		8.955	60.037	6.273	1400.	8.955	61.109	7.664
1600.		8.955	62.038	9.055	1800.	8.955	62.857	10.446
2000.		8.955	63.590	11.838	2200.	8.955	64.259	13.229
2400.		8.955	64.858	14.620	2600.	8.955	65.415	16.011
2800.		8.955	65.930	17.402	3000.	8.955	66.410	18.793
CO2010	44.01	-92.141						
0.		8.955	39.31	-2.074	50.	8.955	39.31	-1.725
100.		8.955	44.131	-1.378	150.	8.955	46.951	-1.030
200.		8.955	48.952	-0.682	250.	8.955	50.504	-0.334
300.		8.955	51.772	0.013	400.	8.955	53.773	0.709
500.		8.955	55.325	1.404	600.	8.955	56.593	2.100
700.		8.955	57.665	2.796	800.	8.955	58.594	3.491
900.		8.955	59.413	4.187	1000.	8.955	60.146	4.882
1200.		8.955	61.414	6.273	1400.	8.955	62.487	7.664
1600.		8.955	63.415	9.055	1800.	8.955	64.235	10.446
2000.		8.955	64.967	11.838	2200.	8.955	65.63	13.229
2400.		8.955	66.235	14.620	2600.	8.955	66.792	16.011
2800.		8.955	67.308	17.402	3000.	8.955	67.788	18.793
CO2020	44.01	-93.284						
0.		8.955	40.115	-2.074	50.	8.955	40.115	-1.725
100.		8.955	44.936	-1.378	150.	8.955	47.757	-1.030
200.		8.955	49.756	-0.682	250.	8.955	51.310	-0.334

500.	0.955	52.272	9.951	4000.	0.955	54.579	0.709
600.	0.955	56.131	1.404	5000.	0.955	57.399	2.100
700.	0.955	58.471	2.796	6000.	0.955	59.400	3.491
900.	0.955	59.419	4.187	10000.	0.955	60.952	4.882
1200.	0.955	62.226	6.273	14000.	0.955	63.292	7.664
1600.	0.955	64.221	9.055	18000.	0.955	64.040	10.446
2000.	0.955	65.773	11.838	22000.	0.955	66.436	13.229
2400.	0.955	66.041	14.620	26000.	0.955	67.590	16.011
2800.	0.955	68.115	17.402	30000.	0.955	68.595	18.793
CO2030	44.01	-88.931					
0.	0.955	40.687	-2.074	50.	0.955	40.687	-1.725
100.	0.955	45.508	-1.376	150.	0.955	48.329	-1.030
200.	0.955	50.329	-0.682	250.	0.955	51.682	-0.334
300.	0.955	53.150	0.013	400.	0.955	55.151	0.709
500.	0.955	56.703	1.404	600.	0.955	57.971	2.100
700.	0.955	59.043	2.796	800.	0.955	59.972	3.491
900.	0.955	60.791	4.187	1000.	0.955	61.524	4.882
1200.	0.955	62.792	6.273	1400.	0.955	63.864	7.664
1600.	0.955	64.793	9.055	1800.	0.955	65.612	10.446
2000.	0.955	66.345	11.838	2200.	0.955	67.008	13.229
2400.	0.955	67.613	14.620	2600.	0.955	68.170	16.011
2800.	0.955	68.685	17.402	3000.	0.955	69.165	18.793
CO2110	44.01	-88.111					
0.	0.955	39.31	-2.074	50.	0.955	39.31	-1.725
100.	0.955	44.131	-1.376	150.	0.955	46.951	-1.030
200.	0.955	48.952	-0.682	250.	0.955	50.304	-0.334
300.	0.955	51.772	0.013	400.	0.955	53.773	0.709
500.	0.955	55.325	1.404	600.	0.955	56.593	2.100
700.	0.955	57.665	2.796	800.	0.955	58.594	3.491
900.	0.955	59.413	4.187	1000.	0.955	60.146	4.882
1200.	0.955	61.414	6.273	1400.	0.955	62.487	7.664
1600.	0.955	63.415	9.055	1800.	0.955	64.235	10.446
2000.	0.955	64.967	11.838	2200.	0.955	65.63	13.229
2400.	0.955	66.235	14.620	2600.	0.955	66.792	16.011
2800.	0.955	67.308	17.402	3000.	0.955	67.788	18.793
HE	4.003	0.					
0.	4.968	21.255	-1.481	50.	4.968	21.255	-1.233
100.	4.968	24.698	-0.984	150.	4.968	26.128	-0.736
200.	4.968	28.142	-0.488	250.	4.968	29.048	-0.239
300.	4.968	30.156	0.009	400.	4.968	31.588	0.506
500.	4.968	32.694	1.003	600.	4.968	33.600	1.500
700.	4.968	34.366	1.996	800.	4.968	35.029	2.493
900.	4.968	35.614	2.990	1000.	4.968	36.138	3.487
1200.	4.968	37.044	4.481	1400.	4.968	37.809	5.474
1600.	4.968	38.473	6.468	1800.	4.968	39.058	7.461
2000.	4.968	39.581	8.455	2200.	4.968	40.055	9.449
2400.	4.968	40.467	10.442	2600.	4.968	40.885	11.436
2800.	4.968	41.253	12.430	3000.	4.968	41.596	13.423
O	2.015	53.252					
0.	4.968	20.387	-1.482	50.	4.968	20.387	-1.233
100.	4.968	24.031	-0.985	150.	4.968	26.045	-0.736
200.	4.968	27.475	-0.488	250.	4.968	28.583	-0.240
300.	4.968	29.489	0.009	400.	4.968	30.918	0.506
500.	4.968	32.027	1.002	600.	4.968	32.933	1.499
700.	4.968	33.699	1.996	800.	4.968	34.362	2.493
900.	4.968	34.947	2.990	1000.	4.968	35.471	3.480
1200.	4.968	36.376	4.480	1400.	4.968	37.142	5.474
1600.	4.968	37.806	6.467	1800.	4.968	38.391	7.461

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  2000.        4.968    38.914     6.455  2200.        4.968    39.388     9.448
  2400.        4.968    39.620    10.442  2600.        4.968    40.218    11.435
  2800.        4.968    40.586    12.429  3000.        4.968    40.929    13.423
F        19.        18.34
     0.        5.068    29.481    -1.558    50.        5.068    29.481    -1.495
   100.        5.068    32.116    -1.059   150.        5.325    34.201    -0.803
   200.        5.403    35.746    -0.534   250.        5.430    36.960    -0.262
   300.        5.436    37.951     0.010   400.        5.561    39.505     0.550
   500.        5.282    40.693     1.082   600.        5.218    41.650     1.607
   700.        5.169    42.45      2.126   800.        5.133    43.138     2.641
   900.        5.105    43.741     3.153  1000.        5.083    44.277     3.663
  1200.        5.052    45.201     4.676  1400.        5.032    45.978     5.684
  1600.        5.018    46.649     6.689  1800.        5.009    47.24      7.692
  2000.        5.001    47.767     8.693  2200.        4.996    48.244     9.692
  2400.        4.992    48.678    10.691  2600.        4.988    49.078    11.689
  2800.        4.986    49.447    12.687  3000.        4.984    49.791    13.683
M1
  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
  1.0  1.0
M2
  1.0  1.0  1.0  1.0  1.0  1.0  1.0 1.75  1.0  1.0  1.0  1.0  1.0  1.0  1.0
 20.0  1.0
M3
  0.0  0.0                 1.0  1.0                 1.0  1.0  1.0  1.0  1.0

M5
  1.0  1.0  1.0  1.0  1.0  0.0  0.0            1.7

M7

  1.0  1.0
M10
 53.0 53.0 53.0 53.0 53.0  0.0  0.0  1.0       53.0
      53.0
M11
  1.0  1.0  1.0  1.0  1.0  1.0  1.0  2.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.5
  2.0  1.0
M12
  1.0  1.0  1.0  1.0  1.0  1.0  1.0       1.0  1.0  1.0  1.0  1.0  1.0  1.0
       1.0
M14
                                      1.0
  1.0
F2     +M1            =F      +F      +M1            53 8.30-11       - 35300.0
D      +D      +M2    =D2     +M2                    22 2.80-30 1.0
DF(0)  +M1            =D      +F      +M1            54 2.00-06 1.0   -137130.0
F      +D2            =DF(1)  +D                     13 1.24-11       -  1460.0
F      +D2            =DF(2)  +D                     13 2.88-11       -  1460.0
F      +D2            =DF(3)  +D                     13 4.43-11       -  1460.0
F      +D2            =DF(4)  +D                     13 3.14-11       -  1460.0
D      +F2            =DF(1)  +F                     13 8.30-12       -  2400.0
D      +F2            =DF(2)  +F                     13 1.40-11       -  2400.0
D      +F2            =DF(3)  +F                     13 2.08-11       -  2400.0
D      +F2            =DF(4)  +F                     13 2.96-11       -  2400.0
DF(1)  +M3            =DF(0)  +M3                    62 6.64-21-2.2
DF(2)  +M3            =DF(1)  +M3                    62 1.33-20-2.2
DF(3)  +M3            =DF(2)  +M3                    62 1.99-20-2.2
DF(4)  +M3            =DF(3)  +M3                    62 2.66-20-2.2
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DF(1) +M5          =DF(0) +M5                  62 7.47-20-2.2
DF(2) +M5          =DF(1) +M5                  62 1.49-19-2.2
DF(3) +M5          =DF(2) +M5                  62 2.24-19-2.2
DF(4) +M5          =DF(3) +M5                  62 2.99-19-2.2
DF(1) +M6          =DF(0) +M6                  62 8.80-08 2.0
DF(2) +M6          =DF(1) +M6                  62 1.76-07 2.0
DF(3) +M6          =DF(2) +M6                  62 2.64-07 2.0
DF(4) +M6          =DF(3) +M6                  62 3.52-07 2.0
DF(1) +M7          =DF(0) +M7                  62 4.70-15-1.0
DF(2) +M7          =DF(1) +M7                  62 8.20-15-1.0
DF(3) +M7          =DF(2) +M7                  62 1.40-14-1.0
DF(4) +M7          =DF(3) +M7                  62 2.30-14-1.0
DF(1) +DF(1)       =DF(0) +DF(2)               12 6.26-16-1.5
DF(2) +DF(2)       =DF(1) +DF(3)               12 1.88-15-1.5
DF(3) +DF(3)       =DF(2) +DF(4)               12 3.83-15-1.5
DF(1) +DF(2)       =DF(0) +DF(3)               12 5.79-16-1.5
DF(2) +DF(3)       =DF(1) +DF(4)               12 1.57-15-1.5
DF(1) +DF(3)       =DF(0) +DF(4)               12 4.86-16-1.5
DF(1) +CO2000      =DF(0) +CO2001              12 3.40-10 0.7
DF(2) +CO2000      =DF(1) +CO2001              12 6.80-10 0.7
DF(3) +CO2000      =DF(2) +CO2001              12 1.00-09 0.7
DF(4) +CO2000      =DF(3) +CO2001              12 1.40-09 0.7
CO2001+CO2000      =CO2100+CO2010              14 5.65-23-2.5  -   390.0
CO2001+CO2000      =CO2020+CO2010              14 2.00-23-2.5  -  1000.0
CO2110+CO2000      =CO2100+CO2010              12 1.25-13-0.5
CO2030+CO2000      =CO2100+CO2010              12 1.83-15-0.5
CO2030+CO2000      =CO2020+CO2010              12 3.10-13-0.5
CO2100+CO2000      =CO2010+CO2010              12 2.50-13-0.5
CO2020+CO2000      =CO2010+CO2010              12 1.40-12-0.5
CO2001+M3          =CO2110+M3                  64 1.06-27-4.8      1484.0
CO2001+M10         =CO2110+M10                 62 2.00-18-1.5
CO2001+M3          =CO2030+M3                  64 8.10-31-5.6      1484.0
CO2001+M10         =CO2030+M10                 62 1.50-21-2.3
CO2110+M11         =CO2030+M11                 62 4.30-17-1.5
CO2110+M11         =CO2020+M11                 64 4.50-27-4.2  -   903.0
CO2110+M11         =CO2020+M11                 64 8.80-20-2.5  -  4410.0
CO2110+M11         =CO2100+M11                 64 8.60-24-3.8  -   549.0
CO2030+M11         =CO2020+M11                 64 9.30-22-3.3  -  1230.0
CO2030+M11         =CO2100+M11                 64 1.06-21-3.0  -  1060.0
CO2100+M11         =CO2020+M11                 62 7.90-16-1.5
CO2100+M12         =CO2010+M12                 64 5.65-22-3.3  -  1480.0
CO2020+M14         =CO2010+M14                 62 5.80-10 1.0
CO2020+M12         =CO2010+M12                 64 2.08-21-3.2  -  1350.0
CO2100+M14         =CO2010+M14                 62 2.70-10 1.0
CO2010+M12         =CO2000+M12                 64 3.36-26-4.2      1130.0
 0.25       0.0        0.0001     26.0
 21.05      2998.25    45.71      11.007     0.293      1.74       252.0       1.0
 0.70372    0.02745    3.3     -4 -0.013     1.013
   0   0    0   0
 44.01      961.0      0.0        0.3906     0.0031     0.0        0.0         2.0
 0.137684   0.0        0.0        0.0        1.0
   0
 20.0       1.94554+5  961.0      0.381
                                              0.065      0.251
                                   0.438                 0.246
 20.0       1.2192 +5  357.0      0.381
                                   0.5                              0.5
 25.0
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MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

THE KNOWN PARAMETER FOR THIS CASE IS PRESS.

24 18 60 1 9 4 1 0 8 0 2 1 1 -8 2 1

	REACTIONS BEING CONSIDERED	KR=A*EXP(B/RT**M)/T**N	A	N	B	M	R-TYPE	K-TYPE
1	F2 + M1 = F + F + M1		5.001E+13	-0.8	-35300.0	-0.8	5	3
2	D + D + M2 = D2 + M2		1.016E+18	1.0	-0.0	-0.0	2	2
3	DF(0) + M1 = D + F + M1		1.205E+18	1.0	-137130.0	-0.0	5	4
4	F + D2 = DF(1) + D		7.471E+12	-0.0	-1460.0	-0.0	1	3
5	F + D2 = DF(2) + D		1.735E+13	-0.0	-1460.0	-0.0	1	3
6	F + D2 = DF(3) + D		2.669E+13	-0.0	-1460.0	-0.0	1	3
7	F + D2 = DF(4) + D		1.892E+13	-0.0	-1460.0	-0.0	1	3
8	D + F2 = DF(1) + F		5.081E+12	-0.0	-2400.0	-0.0	1	3
9	D + F2 = DF(2) + F		8.435E+12	-0.0	-2400.0	-0.0	1	3
10	D + F2 = DF(3) + F		1.253E+13	-0.0	-2400.0	-0.0	1	3
11	D + F2 = DF(4) + F		1.783E+13	-0.0	-2400.0	-0.0	1	3
12	DF(1) + M3 = DF(0) + M3		4.001E+03	-2.2	-0.0	-0.0	6	2
13	DF(2) + M3 = DF(1) + M3		8.013E+03	-2.2	-0.0	-0.0	6	2
14	DF(3) + M3 = DF(2) + M3		1.199E+04	-2.2	-0.0	-0.0	6	2
15	DF(4) + M3 = DF(3) + M3		1.603E+04	-2.2	-0.0	-0.0	6	2
16	DF(1) + M5 = DF(0) + M5		4.501E+04	-2.2	-0.0	-0.0	6	2
17	DF(2) + M5 = DF(1) + M5		8.977E+04	-2.2	-0.0	-0.0	6	2
18	DF(3) + M5 = DF(2) + M5		1.350E+05	-2.2	-0.0	-0.0	6	2
19	DF(4) + M5 = DF(3) + M5		1.801E+05	-2.2	-0.0	-0.0	6	2
20	DF(1) + M5 = DF(0) + M5		5.302E+16	2.0	-0.0	-0.0	6	2
21	DF(2) + M5 = DF(1) + M5		1.060E+17	2.0	-0.0	-0.0	6	2
22	DF(3) + M5 = DF(2) + M5		1.591E+17	2.0	-0.0	-0.0	6	2
23	DF(4) + M5 = DF(3) + M5		2.121E+17	2.0	-0.0	-0.0	6	2
24	DF(1) + M7 = DF(0) + M7		2.832E+09	-1.0	-0.0	-0.0	6	2
25	DF(2) + M7 = DF(1) + M7		4.941E+09	-1.0	-0.0	-0.0	6	2
26	DF(3) + M7 = DF(2) + M7		8.435E+09	-1.0	-0.0	-0.0	6	2
27	DF(4) + M7 = DF(3) + M7		1.386E+10	-1.0	-0.0	-0.0	6	2
28	DF(1) + DF(1) = DF(0) + DF(2)		3.772E+08	-1.5	-0.0	-0.0	1	2
29	DF(2) + DF(2) = DF(1) + DF(3)		1.133E+09	-1.5	-0.0	-0.0	1	2
30	DF(3) + DF(3) = DF(2) + DF(4)		2.388E+09	-1.5	-0.0	-0.0	1	2
31	DF(1) + DF(2) = DF(0) + DF(3)		3.488E+08	-1.5	-0.0	-0.0	1	2
32	DF(2) + DF(3) = DF(1) + DF(4)		9.459E+08	-1.5	-0.0	-0.0	1	2

33	DF(1) + DF(3)	= DF(0) + DF(4)	2.928E+08	-1.5	-0.0	-0.0	1	2
34	DF(1) + CO2000	= DF(0) + CO2001	2.049E+14	.7	-0.0	-0.0	1	2
35	DF(2) + CO2000	= DF(1) + CO2001	4.097E+14	.7	-0.0	-0.0	1	2
36	DF(3) + CO2000	= DF(2) + CO2001	6.025E+14	.7	-0.0	-0.0	1	2
37	DF(4) + CO2000	= DF(3) + CO2001	8.435E+14	.7	-0.0	-0.0	1	2
38	CO2001+ CO2000	= CO2100+ CO2010	3.404E+01	-2.5	-390.0	-0.0	1	4
39	CO2001+ CO2000	= CO2020+ CO2010	1.205E+01	-2.5	-1000.0	-0.0	1	4
40	CO2110+ CO2000	= CO2100+ CO2010	7.531E+10	-.5	-0.0	-0.0	1	2
41	CO2030+ CO2000	= CO2100+ CO2010	1.103E+09	-.5	-0.0	-0.0	1	2
42	CO2030+ CO2000	= CO2020+ CO2010	1.868E+11	-.5	-0.0	-0.0	1	2
43	CO2100+ CO2000	= CO2010+ CO2010	1.506E+11	-.5	-0.0	-0.0	1	2
44	CO2020+ CO2000	= CO2010+ CO2010	8.435E+11	-.5	-0.0	-0.0	1	2
45	CO2001+ M3	= CO2110+ M3	6.387E-04	-4.8	1484.0	-0.0	6	4
46	CO2001+ M10	= CO2110+ M10	1.205E+06	-1.5	-0.0	-0.0	6	2
47	CO2001+ M3	= CO2030+ M3	4.880E-07	-5.6	1484.0	-0.0	6	4
48	CO2001+ M10	= CO2030+ M10	9.038E+02	-2.3	-0.0	-0.0	6	2
49	CO2110+ M11	= CO2030+ M11	2.591E+07	-1.5	-0.0	-0.0	6	2
50	CO2110+ M11	= CO2020+ M11	2.711E-03	-4.2	-903.0	-0.0	6	4
51	CO2110+ M11	= CO2020+ M11	5.302E+04	-2.5	-4410.0	-0.0	6	4
52	CO2110+ M11	= CO2100+ M11	5.182E+00	-3.8	-549.0	-0.0	6	4
53	CO2030+ M11	= CO2020+ M11	5.603E+02	-3.3	-1230.0	-0.0	6	4
54	CO2030+ M11	= CO2100+ M11	6.387E+02	-3.0	-1060.0	-0.0	6	4
55	CO2100+ M11	= CO2020+ M11	4.760E+08	-1.5	-0.0	-0.0	6	2
56	CO2100+ M12	= CO2010+ M12	3.404E+02	-3.3	-1480.0	-0.0	6	4
57	CO2020+ M14	= CO2010+ M14	3.495E+14	1.0	-0.0	-0.0	6	2
58	CO2020+ M12	= CO2010+ M12	1.253E+03	-3.2	-1350.0	-0.0	6	4
59	CO2100+ M14	= CO2010+ M14	1.627E+14	1.0	-0.0	-0.0	6	2
60	CO2010+ M12	= CO2000+ M12	2.024E-02	-4.2	1130.0	-0.0	6	4

CATALYTIC SPECIES BEING CONSIDERED

```
M1    = 1.00 DF(0) , 1.00 DF(1) , 1.00 DF(2) , 1.00 DF(3) , 1.00 DF(4) , 1.00 CO2100, 1.00 CO2001,
        1.00 D2    , 1.00 F2    , 1.00 HF    , 1.00 CO2000, 1.00 CO2010, 1.00 CO2020, 1.00 CO2030,
        1.00 CO2110, 1.00 HE    , 1.00 D     , 1.00 F     ,

M2    = 1.00 DF(0) , 1.00 DF(1) , 1.00 DF(2) , 1.00 DF(3) , 1.00 DF(4) , 1.00 CO2100, 1.00 CO2001,
        1.75 D2    , 1.00 F2    , 1.00 HF    , 1.00 CO2000, 1.00 CO2010, 1.00 CO2020, 1.00 CO2030,
        1.00 CO2110,-0.00 HE    ,20.00 D     , 1.00 F     ,

M3    = 0.00 DF(0) , 0.00 DF(1) ,-0.00 DF(2) ,-0.00 DF(3) ,-0.00 DF(4) , 1.00 CO2100, 1.00 CO2001,
       -0.00 D2    ,-0.00 F2    ,-0.00 HF    , 1.00 CO2000, 1.00 CO2010, 1.00 CO2020, 1.00 CO2030,
        1.00 CO2110,-0.00 HE    ,-0.00 D     ,-0.00 F     ,

M5    = 1.00 DF(0) , 1.00 DF(1) , 1.00 DF(2) , 1.00 DF(3) , 1.00 DF(4) , 0.00 CO2100, 0.00 CO2001,
       -0.00 D2    ,-0.00 F2    , 1.70 HF    ,-0.00 CO2000,-0.00 CO2010,-0.00 CO2020,-0.00 CO2030,
       -0.00 CO2110,-0.00 HE    ,-0.00 D     ,-0.00 F     ,

M7    =-0.00 DF(0) ,-0.00 DF(1) ,-0.00 DF(2) ,-0.00 DF(3) ,-0.00 DF(4) ,-0.00 CO2100,-0.00 CO2001,
       -0.00 D2    ,-0.00 F2    ,-0.00 HF    ,-0.00 CO2000,-0.00 CO2010,-0.00 CO2020,-0.00 CO2030,
       -0.00 CO2110,-0.00 HE    , 1.00 D     , 1.00 F     ,

M10   =53.00 DF(0) ,53.00 DF(1) ,53.00 DF(2) ,53.00 DF(3) ,53.00 DF(4) , 0.00 CO2100, 0.00 CO2001,
        1.00 D2    ,-0.00 F2    ,53.00 HF    ,-0.00 CO2000,-0.00 CO2010,-0.00 CO2020,-0.00 CO2030,
       -0.00 CO2110,-0.00 HE    ,-0.00 D     ,53.00 F     ,

M11   = 1.00 DF(0) , 1.00 DF(1) , 1.00 DF(2) , 1.00 DF(3) , 1.00 DF(4) , 1.00 CO2100, 1.00 CO2001,
        2.00 D2    , 1.00 F2    , 1.00 HF    , 1.00 CO2000, 1.00 CO2010, 1.00 CO2020, 1.00 CO2030,
        1.00 CO2110, 1.50 HE    , 2.00 D     , 1.00 F     ,

M12   = 1.00 DF(0) , 1.00 DF(1) , 1.00 DF(2) , 1.00 DF(3) , 1.00 DF(4) , 1.00 CO2100, 1.00 CO2001,
       -0.00 D2    , 1.00 F2    , 1.00 HF    , 1.00 CO2000, 1.00 CO2010, 1.00 CO2020, 1.00 CO2030,
        1.00 CO2110,-0.00 HE    ,-0.00 D     , 1.00 F     ,

M14   =-0.00 DF(0) ,-0.00 DF(1) ,-0.00 DF(2) ,-0.00 DF(3) ,-0.00 DF(4) ,-0.00 CO2100,-0.00 CO2001,
        1.00 D2    ,-0.00 F2    ,-0.00 HF    ,-0.00 CO2000,-0.00 CO2010,-0.00 CO2020,-0.00 CO2030,
       -0.00 CO2110,-0.00 HE    , 1.00 D     ,-0.00 F     ,
```

```
THE KNOWN DATA COEFFICIENTS ARE
    1    .20000E+02  -0.          -0.          -0.          -0.          -0.          -0.          -0.
    2    .20000E+02  -0.          -0.          -0.          -0.          -0.          -0.          -0.
    3    .77113E-01  -0.          -0.          -0.          -0.          -0.          -0.          -0.
    4    .99000E+00  -0.          -0.          -0.          -0.          -0.          -0.          -0.
    5    .95700E+00  -0.          -0.          -0.          -0.          -0.          -0.          -0.
    6    .10000E-01  -0.          -0.          -0.          -0.          -0.          -0.          -0.
    7    .10000E-01  -0.          -0.          -0.          -0.          -0.          -0.          -0.

PRINTX=  .25000E+00 X0= 0.          DX=  .10000E-03 XMAX=  .26000E+02

WLM=  .21050E+02 WE=  .29983E+04 WEXE=  .45710E+02 BE=  .11007E+02 AE=  .29300E+00 RAS=  .17400E+01 RBS=  .25200E+03 SYMN=  .10000E+01
 AB=  .70372E+00 BB=  .27450E-01 CB=  .33000E-03 AV= -.13000E-01 BV=  .10130E+01

WLM=  .44010E+02 WE=  .96100E+03 WEXE= 0.          BE=  .39060E+00 AE=  .31000E-02 RAS= 0.          RBS= 0.          SYMN=  .20000E+01
 AB=  .13768E+00 BB= 0.          CB= 0.          AV= 0.          BV=  .10000E+01

LOWER LEVEL ROTATIONAL QUANTUM NUMBERS

    0    0    0    0    0    0
```

MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

X (CM) 0. AREA (CM**2/CM) .76200E+00 DELTAX (CM) .10000E-03 MDOT (G/SEC/CM) .15721E+01

STREAM DATA

S	U(CM/SEC)	P(TORR)	T(DEG K)	H(CAL/G)	RHO(G/CC)	R(CM)	MOL. WT.	M(G/SEC/CM)	CP(CAL/G/K)
1	.19455E+06	.20000E+02	.58100E+03	-.73352E+03	.76845E-05	.38100E+00	.13919E+02	.56962E+00	.41385E+00
GAMA	.15262E+01 SOS	.72773E+05 MACH NO.	.26735E+01						
2	.12192E+06	.20000E+02	.35700E+03	-.19407E+04	.21581E-04	.38100E+00	.24020E+02	.10025E+01	.29016E+00
GAMA	.13985E+01 SOS	.41569E+05 MACH NO.	.29330E+01						

SPECIES MOLE FRACTIONS

1											
	DF(0)	.13919E-28	DF(1)	.13919E-28	DF(2)	.13919E-28	DF(3)	.13919E-28	DF(4)	.13919E-28	CO2100	.13919E-28
	CO2001	.13919E-28	D2	.13919E-28	F2	.65000E-01	HF	.25100E+00	CO2000	.13919E-28	CO2010	.13919E-28
	CO2020	.13919E-28	CO2030	.13919E-28	CO2110	.13919E-28	HE	.43800E+00	D	.13919E-28	F	.24600E+00
2											
	DF(0)	.24020E-28	DF(1)	.24020E-28	DF(2)	.24020E-28	DF(3)	.24020E-28	DF(4)	.24020E-28	CO2100	.24020E-28
	CO2001	.24020E-28	D2	.50000E+00	F2	.24020E-28	HF	.24020E-28	CO2000	.50000E+00	CO2010	.24020E-28
	CO2020	.24020E-28	CO2030	.24020E-28	CO2110	.24020E-28	HE	.24020E-28	D	.24020E-28	F	.24020E-28

MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

X (CM) 0. AREA (CM**2/CM) .76200E+00 DELTAX (CM) .10000E-03 MDOT (G/SEC/CM) .15721E+01

MULTI-LEVEL CL-INFORMATION

ALFA(1/CM)	LENGTH(CM)	R1	R2	A1	A2	T1	T2
1.080044E-03	2.500000E+01	.990000	.957000	0.000000	0.000000	.010000	.043000

K	IL	J	AVGN (1/CM)	LAMBDA (CM)	I(INTRNL) (W/SQCM)	I(OUT) (W/SQCM)	I(USEFUL) (W/SQCM)	PWR(OUT)/H (KW/CM)	PWR(USF)/H (KW/CM)
1	0	7	8.467615E-29	3.646339E-04					
2	0	7	1.667901E-28	3.766253E-04					
3	0	7	2.448980E-28	3.894322E-04					
4	0	7	3.186769E-28	4.031408E-04					
6	0	36	7.855736E-30	1.075039E-03					

ILS= 0 IFLAG= 2 X= 0. RAOT=

1	0	7	8.467615E-29	0.	7.878953E-29	8.250610E-29
2	0	7	1.667901E-28	0.	1.570179E-28	1.608233E-28
3	0	7	2.448980E-28	0.	2.332750E-28	2.336551E-28
4	0	7	3.186769E-28	0.	3.071664E-28	3.008184E-28
6	0	36	7.855736E-30	0.	7.748832E-30	7.849202E-30

```
TRANSITION NO. 3  GAIN ABOVE THRESHOLD
X =  3.000000E-04   AVGN =  1.287597E-03   JMAX =  7   RETURN TO PREVIOUS X
TRANSITION NO. 3  GAIN ABOVE THRESHOLD
X =  3.168708E-04   AVGN =  1.292601E-03   JMAX =  7   RETURN TO PREVIOUS X
TRANSITION NO. 3  GAIN ABOVE THRESHOLD
X =  3.076818E-04   AVGN =  1.115759E-03   JMAX =  8   RETURN TO PREVIOUS X
TRANSITION NO. 3  GAIN ABOVE THRESHOLD
X =  3.396975E-04   AVGN =  1.390973E-03   JMAX =  8   RETURN TO PREVIOUS X
TRANSITION NO. 3  GAIN ABOVE THRESHOLD
X =  3.421732E-04   AVGN =  1.103695E-03   JMAX =  8   RETURN TO PREVIOUS X
TRANSITION NO. 3  GAIN ABOVE THRESHOLD
X =  3.902622E-04   AVGN =  1.696828E-03   JMAX =  8   RETURN TO PREVIOUS X
TRANSITION NO. 3  GAIN ABOVE THRESHOLD
X =  3.398437E-04   AVGN =  1.081331E-03   JMAX =  8   RETURN TO PREVIOUS X
TRANSITION NO. 3  GAIN ABOVE THRESHOLD
X =  4.339541E-04   AVGN =  2.495574E-03   JMAX =  8   RETURN TO PREVIOUS X
TRANSITION NO. 3  GAIN ABOVE THRESHOLD
X =  3.397755E-04   AVGN =  1.080299E-03   JMAX =  8   RETURN TO PREVIOUS X
TRANSITION NO. 3   *** THRESHOLD ***  X = 3.397587E-04 (FT)
```

MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

X (CM) 0.

K	1	RAI	0.	RAO	0.	RAU	0.	PWRO	0.	PWRU	0.
K	2	RAI	0.	RAO	0.	RAU	0.	PWRO	0.	PWRU	0.
K	3	RAI	0.	RAO	0.	RAU	0.	PWRO	0.	PWRU	0.
K	4	RAI	0.	RAO	0.	RAU	0.	PWRO	0.	PWRU	0.
K	6	RAI	0.	RAO	0.	RAU	0.	PWRO	0.	PWRU	0.

RAIT 0. RAOT 0. RAUT 0. TPWRO 0. TPWRO 0. STPWRO 0. STPWRU 0.

MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

X (CM) .33976E-03 AREA (CM**2/CM) .37463E+01 DELTAX (CM) .24449E-05 MDOT (G/SEC/CM) .15721E+01

STREAM DATA

S	U(CM/SEC)	P(TORR)	T(DEG K)	H(CAL/G)	RHO(G/CC)	R(CM)	MOL. WT.	M(G/SEC/CM)	CP(CAL/G/K)
1	.70493E+05	.20000E+02	.11111E+04	-.11126E+04	.59528E-05	.37463E+01	.20621E+02	.15721E+01	.31663E+00

GAMA .14371E+01 SOS .80235E+05 MACH NO. .87858E+00

SPECIES MOLE FRACTIONS

1

DF(0)	.77799E-08	DF(1)	.34328E-04	DF(2)	.79716E-04	DF(3)	.12255E-03	DF(4)	.86781E-04	CO2100	.59112E-10
CO2001	.62995E-07	D2	.23128E+00	F2	.34891E-01	HF	.13473E+00	CO2000	.23160E+00	CO2010	.30048E-05
CO2020	.38359E-09	CO2030	.18602E-11	CO2110	.97588E-11	HE	.23511E+00	D	.32328E-03	F	.13173E+00

MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

```
X (CM)     .33976E-03

K       1 RAI  0.           RAC  0.           RAU  0.           PWRO  0.           PWRU  0.

K       2 RAI  0.           RAO  0.           RAU  0.           PWRO  0.           PWRU  0.

K       3 RAI   .25503E+06 RAO   .68861E+04 RAU   .43012E+04 PWRO  0.           PWRU  0.

K       4 RAI  0.           RAO  0.           RAU  0.           PWRO  0.           PWRU  0.

K       6 RAI  0.           RAO  0.           RAU  0.           PWRO  0.           PWRU  0.

 RAIT  .25503E+06 RAOT  .68861E+04 RAUT  .43012E+04 TPWRO 0.          TPWRO 0.          STPWRO 0.          STPWRU 0.

   TRANSITION NO. 2  GAIN ABOVE THRESHOLD

   X =  4.622039E-04   AVGN =  2.457174E-03   JMAX =  7   RETURN TO PREVIOUS X

   J-SHIFT( 1)ENCOUNTERED ON TRANSITION NO. 3,  X= 3.686391E-04
      1.080040E-03   1.080658E-03   1.036643E-03
      1.036087E-03   1.080041E-03   1.075990E-03
   RETURN TO X= 3.622039E-04  DX= 1.833632E-07

   TRANSITION NO. 2  GAIN ABOVE THRESHOLD

   X =  3.733818E-04   AVGN =  1.152417E-03   JMAX =  7   RETURN TO PREVIOUS X

   TRANSITION NO. 2  GAIN ABOVE THRESHOLD

   X =  3.819850E-04   AVGN =  1.282132E-03   JMAX =  7   RETURN TO PREVIOUS X

   TRANSITION NO. 2   *** THRESHOLD ***  X = 3.685865E-04 (FT)
```

MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

X (CM) .33976E-03 AREA (CM**2/CM) .37463E+01 DELTAX (CM) .24449E-05 MDOT (G/SEC/CM) .15721E+01

MULTI-LEVEL CL-INFORMATION

ALFA(1/CM)	LENGTH(CM)	R1	R2	A1	A2	T1	T2
1.080044E-03	2.500000E+01	.990000	.957000	.010000	.010000	-.000000	.033000

K	IL	J	AVGN (1/CM)	LAMBDA (CM)	I(INTRNL) (W/SQCM)	I(OUT) (W/SQCM)	I(USEFUL) (W/SQCM)	PWR(OUT)/H (KW/CM)	PWR(USF)/H (KW/CM)
1	0	7	2.207643E-04	3.646339E-04					
2	0	8	6.527346E-04	3.802394E-04					
3	1	8	1.080045E-03	3.932070E-04					
4	0	16	6.768745E-05	4.458629E-04					
6	0	32	1.875913E-07	1.070644E-03					

ILS= 1 IFLAG= 2 X= .33976E-03 RAOT=

1	0	7	2.207643E-04	2.132000E-04	2.157170E-04	2.152335E-04
2	0	8	6.527346E-04	6.303697E-04	6.251018E-04	6.526732E-04
3	1	8	1.080045E-03	1.043044E-03	1.059692E-03	1.053671E-03
4	0	16	6.768745E-05	6.537004E-05	6.299937E-05	6.507816E-05
6	0	32	1.875913E-07	1.780936E-07	1.872664E-07	1.864658E-07

MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

X (CM) .10097E-01 AREA (CM**2/CM) .39521E+01 DELTAX (CM) .10000E-03 MDOT (G/SEC/CM) .15721E+01

STREAM DATA

S	U(CM/SEC)	P(TORR)	T(DEG K)	H(CAL/G)	RHO(G/CC)	R(CM)	MOL. WT.	M(G/SEC/CM)	CP(CAL/G/K)
1	.70493E+05	.20000E+02	.11722E+04	-.11310E+04	.56429E-05	.39521E+01	.20621E+02	.15721E+01	.31641E+00

GAMA .14376E+01 SOS .82421E+05 MACH NO. .85528E+00

SPECIES MOLE FRACTIONS

1

DF(0)	.13617E-01	DF(1)	.91570E-02	DF(2)	.60006E-02	DF(3)	.39503E-02	DF(4)	.26472E-02	CO2100	.50776E-05
CO2001	.33364E-03	D2	.19663E+00	F2	.34500E-01	HF	.13473E+00	CO2000	.23031E+00	CO2010	.93066E-03
CO2020	.23990E-04	CO2030	.19505E-05	CO2110	.39595E-05	HE	.23511E+00	D	.34590E-01	F	.97459E-01

MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

X (CM) .10097E-01 AREA (CM**2/CM) .39521E+01 DELTAX (CM) .10000E-03 MDOT (G/SEC/CM) .15721E+01

MULTI-LEVEL CL-INFORMATION

ALFA(1/CM)	LENGTH(CM)	R1	R2	A1	A2	T1	T2
1.080044E-03	2.500000E+01	.990000	.957000	.010000	.010000	-.000000	.033000

K	IL	J	AVGN (1/CM)	LAMBDA (CM)	I(INTRNL) (W/SQCM)	I(OUT) (W/SQCM)	I(USEFUL) (W/SQCM)	PWR(OUT)/H (KW/CM)	PWR(USF)/H (KW/CM)
1	1	17	1.080026E-03	4.068552E-04					
2	1	18	1.080060E-03	4.263807E-04					
3	1	18	1.080028E-03	4.416083E-04					
4	1	18	1.080030E-03	4.579639E-04					
6	0	34	8.799642E-04	1.072823E-03					

ILS= 4 IFLAG= 2 X= .10097E-01 RAOT=

1	1	17	1.080026E-03	1.080026E-03	9.721065E-04	1.063762E-03
2	1	18	1.080060E-03	1.080022E-03	9.575155E-04	1.080022E-03
3	1	18	1.080028E-03	1.080027E-03	9.835645E-04	1.039807E-03
4	1	18	1.080030E-03	1.080030E-03	9.842736E-04	1.051540E-03
6	0	34	8.799642E-04	8.660719E-04	8.750873E-04	8.786049E-04

MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

X (CM) .10097E-01

K 1 RAI .63182E+06 RAO .17060E+05 RAU .10656E+05 PWRO .20501E+00 PWRU .12805E+00

K 2 RAI .82226E+06 RAO .22202E+05 RAU .13868E+05 PWRO .27436E+00 PWRU .17137E+00

K 3 RAI .66858E+06 RAO .18051E+05 RAU .11275E+05 PWRO .22559E+00 PWRU .14091E+00

K 4 RAI .26681E+06 RAO .72042E+04 RAU .44999E+04 PWRO .89667E-01 PWRU .56008E-01

K 6 RAI 0. RAO 0. RAU 0. PWRO 0. PWRU 0.

RAIT .23894E+07 RAOT .64517E+05 RAUT .40299E+05 TPWRO .79462E+00 TPWRO .49634E+00 STPWRO .79905E-01 STPWRU .49910E-01

TRANSITION NO. 6 GAIN ABOVE THRESHOLD

X = 1.149693E-02 AVGN = 1.080085E-03 JMAX = 34 RETURN TO PREVIOUS X

TRANSITION NO. 6 GAIN ABOVE THRESHOLD

X = 1.159638E-02 AVGN = 1.094677E-03 JMAX = 34 RETURN TO PREVIOUS X

TRANSITION NO. 6 *** THRESHOLD *** X = 1.149666E-02 (FT)

MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

X (CM) .11497E-01 AREA (CM**2/CM) .39786E+01 DELTAX (CM) .43808E-08 MDOT (G/SEC/CM) .15721E+01

STREAM DATA

S	U(CM/SEC)	P(TORR)	T(DEG K)	H(CAL/G)	RHO(G/CC)	R(CM)	MOL. WT.	M(G/SEC/CM)	CP(CAL/G/K)
1	.70493E+05	.20000E+02	.11800E+04	-.11331E+04	.56053E-05	.39786E+01	.20621E+02	.15721E+01	.31639E+00

GAMA .14376E+01 SOS .82698E+05 MACH NO. .85241E+00

SPECIES MOLE FRACTIONS

1

DF(0)	.15293E-01	DF(1)	.10176E-01	DF(2)	.66053E-02	DF(3)	.43154E-02	DF(4)	.28712E-02	CO2100	.68305E-05
CO2001	.41549E-03	D2	.19284E+00	F2	.34393E-01	HF	.13473E+00	CO2000	.23007E+00	CO2010	.10728E-02
CO2020	.31402E-04	CO2030	.28784E-05	CO2110	.56571E-05	HE	.23511E+00	D	.38265E-01	F	.93784E-01

MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

X (CM) .11497E-01 AREA (CM**2/CM) .39786E+01 DELTAX (CM) .43808E-08 MDOT (G/SEC/CM) .15721E+01

MULTI-LEVEL CL-INFORMATION

ALFA(1/CM)	LENGTH(CM)	R1	R2	A1	A2	T1	T2
1.080044E-03	2.500000E+01	.990000	.957000	.010000	.010000	-.000080	.033000

K	IL	J	AVGN (1/CM)	LAMBDA (CM)	I(INTRNL) (W/SQCM)	I(OUT) (W/SQCM)	I(USEFUL) (W/SQCM)	PWR(OUT)/H (KW/CM)	PWR(USF)/H (KW/CM)
1	1	17	1.080029E-03	4.068552E-04					
2	1	18	1.080029E-03	4.263807E-04					
3	1	18	1.080030E-03	4.416083E-04					
4	1	18	1.080032E-03	4.579639E-04					
6	1	34	1.080045E-03	1.072823E-03					

ILS= 5 IFLAG= 2 X= .11497E-01 RAOT=

1	1	17	1.080029E-03	1.080029E-03	1.002300E-03	1.006383E-03
2	1	18	1.080029E-03	1.080029E-03	9.854859E-04	1.025202E-03
3	1	18	1.080030E-03	1.080030E-03	1.010869E-03	9.879435E-04
4	1	18	1.080032E-03	1.080032E-03	1.008472E-03	1.006908E-03
6	1	34	1.080045E-03	1.080044E-03	1.074510E-03	1.077949E-03

MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

X (CM) .11497E-01

K 1 RAI .60260E+06 RAO .16271E+05 RAU .10163E+05 PWRO .22640E+00 PWRU .14142E+00

K 2 RAI .78241E+06 RAO .21126E+05 RAU .13196E+05 PWRO .30224E+00 PWRU .18879E+00

K 3 RAI .63534E+06 RAO .17155E+05 RAU .10715E+05 PWRO .24828E+00 PWRU .15508E+00

K 4 RAI .25341E+06 RAO .68423E+04 RAU .42738E+04 PWRO .98699E-01 PWRU .61650E-01

K 6 RAI .58646E+04 RAO .15835E+03 RAU .98910E+02 PWRO 0. PWRU 0.

RAIT .22796E+07 RAOT .61552E+05 RAUT .38447E+05 TPWRO .87562E+00 TPWRO .54693E+00 STPWRO .88640E-01 STPWRU .55366E-01

J-SHIFT(1)ENCOUNTERED ON TRANSITION NO. 3, X= 1.529834E-02
1.080038E-03 1.080490E-03 9.574321E-04
8.614846E-04 1.080034E-03 1.078738E-03
RETURN TO X= 1.429834E-02 DX= 2.446979E-05

J-SHIFT(1)ENCOUNTERED ON TRANSITION NO. 3, X= 1.527291E-02

X= 1.527291E-02 (CM)EQUAL GAIN FOR ADJACENT J-LEVELS ON TRANSITION NO. 3

MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

X (CM) .15273E-01 AREA (CM**2/CM) .40462E+01 DELTAX (CM) .74621E-04 MDOT (G/SEC/CM) .15721E+01

STREAM DATA

S	U(CM/SEC)	P(TORR)	T(DEG K)	H(CAL/G)	RHO(G/CC)	R(CM)	MOL. WT.	M(G/SEC/CM)	CP(CAL/G/K)
1	.70493E+05	.20000E+02	.12001E+04	-.11382E+04	.55117E-05	.40462E+01	.20621E+02	.15721E+01	.31634E+00

GAMA .14377E+01 SOS .83401E+05 MACH NO. .84523E+00

SPECIES MOLE FRACTIONS

1

DF(0)	.19323E-01	DF(1)	.12660E-01	DF(2)	.81007E-02	DF(3)	.52306E-02	DF(4)	.34397E-02	CO2100	.11724E-03
CO2001	.53699E-03	D2	.18369E+00	F2	.34057E-01	HF	.13473E+00	CO2000	.22939E+00	CO2010	.14709E-02
CO2020	.73988E-04	CO2030	.82819E-05	CO2110	.13204E-04	HE	.23511E+00	D	.47085E-01	F	.84964E-01

MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

X (CM) .15273E-01 AREA (CM**2/CM) .40462E+01 DELTAX (CM) .74621E-04 MDOT (G/SEC/CM) .15721E+01

MULTI-LEVEL CL-INFORMATION

ALFA(1/CM)	LENGTH(CM)	R1	R2	A1	A2	T1	T2
1.080044E-03	2.500000E+01	.990000	.957000	.010000	.010000	-.000000	.033000

K	IL	J	AVGN (1/CM)	LAMBDA (CM)	I(INTRNL) (W/SQCM)	I(OUT) (W/SQCM)	I(USEFUL) (W/SQCM)	PWR(OUT)/H (KW/CM)	PWR(USF)/H (KW/CM)
1	1	17	1.080041E-03	4.068552E-04					
2	1	18	1.080041E-03	4.263807E-04					
3	1	19	1.080049E-03	4.477573E-04					
4	1	18	1.080042E-03	4.579639E-04					
6	1	34	1.079943E-03	1.072823E-03					

ILS= 5 IFLAG= 2 X= .15273E-01 RAOT=

1	1	17	1.080041E-03	1.080033E-03	1.076618E-03	8.681479E-04
2	1	18	1.080041E-03	1.080033E-03	1.055771E-03	8.905124E-04
3	1	19	1.080049E-03	1.080034E-03	9.568058E-04	1.080042E-03
4	1	18	1.080042E-03	1.080035E-03	1.070295E-03	8.949560E-04
6	1	34	1.079943E-03	1.079906E-03	1.076157E-03	1.076169E-03

MULTI-SPECIES LASING TEST CASE - CO2 AND DF RADIATORS

```
X (CM)     .15273E-01

K       1 RAI    .48441E+06 RAO    .13080E+05 RAU    .81698E+04 PWRO    .28177E+00 PWRU    .17600E+00

K       2 RAI    .63809E+06 RAO    .17229E+05 RAU    .10762E+05 PWRO    .37477E+00 PWRU    .23409E+00

K       3 RAI    .51515E+06 RAO    .13910E+05 RAU    .86882E+04 PWRO    .30735E+00 PWRU    .19198E+00

K       4 RAI    .20423E+06 RAO    .55143E+04 RAU    .34444E+04 PWRO    .12201E+00 PWRU    .76210E-01

K       6 RAI    .76609E+04 RAO    .20685E+03 RAU    .12921E+03 PWRO    .68927E-03 PWRU    .43053E-03

 RAIT  .18495E+07 RAOT  .49939E+05 RAUT  .31193E+05 TPWRO  .10866E+01 TPWRO  .67871E+00 STPWRO  .11187E+00 STPWRU  .69874E-01

   J-SHIFT( 1)ENCOUNTERED ON TRANSITION NO. 1,  X= 1.546760E-02
      1.080045E-03   1.080216E-03   9.568949E-04
      8.619045E-04   1.080045E-03   1.080032E-03
   RETURN TO X= 1.446760E-02  DX= 2.309036E-06

   J-SHIFT( 1)ENCOUNTERED ON TRANSITION NO. 1,  X= 1.552797E-02
      1.080042E-03   1.081324E-03   9.584656E-04
      8.619045E-04   1.080045E-03   1.080032E-03
   RETURN TO X= 1.545759E-02  DX= 2.314284E-08

   J-SHIFT( 0)ENCOUNTERED ON TRANSITION NO. 2,  X= 1.545830E-02

   X= 1.545830E-02 (CM)EQUAL GAIN FOR ADJACENT J-LEVELS ON TRANSITION NO. 2
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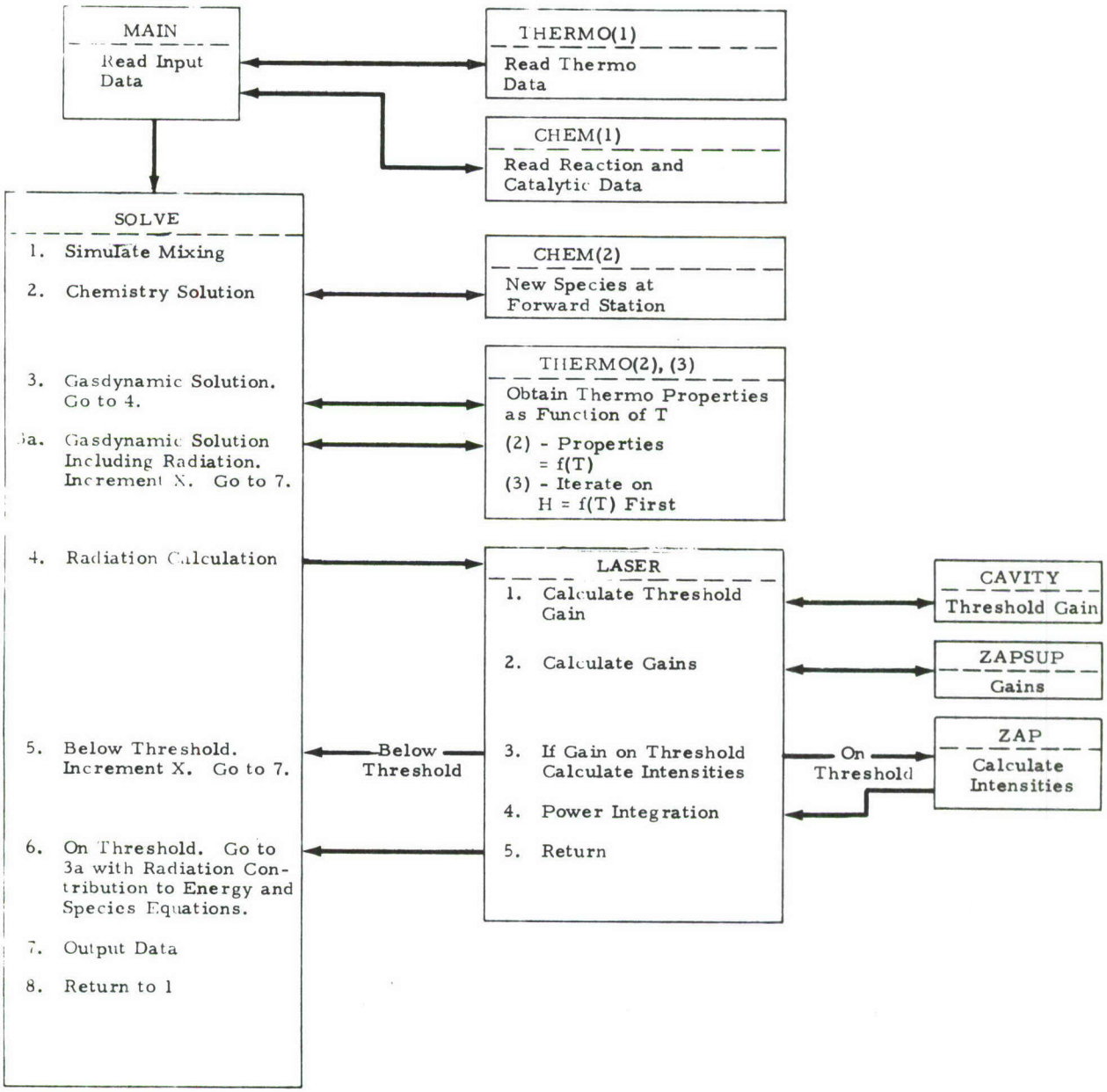
Appendix D
ODLAMP Flow Chart

Appendix D


MAIN
Read Input Data
THERMO(1)
Read Thermo Data
CHEM(1)
Read Reaction and Catalytic Data
SOLVE
1. Simulate Mixing
2. Chemistry Solution
CHEM(2)
New Species at Forward Station
3. Gasdynamic Solution. Go to 4.
3a. Gasdynamic Solution Including Radiation. Increment X. Go to 7.
THERMO(2), (3)
Obtain Thermo Properties as Function of T
(2) - Properties = f(T)
(3) - Iterate on H = f(T) First
4. Radiation Calculation
LASER
1. Calculate Threshold Gain
2. Calculate Gains
3. If Gain on Threshold Calculate Intensities
4. Power Integration
5. Return
CAVITY
Threshold Gain
ZAPSUP
Gains
ZAP
Calculate Intensities
On Threshold
5. Below Threshold. Increment X. Go to 7.
Below Threshold
6. On Threshold. Go to 3a with Radiation Contribution to Energy and Species Equations.
7. Output Data
8. Return to 1